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of the
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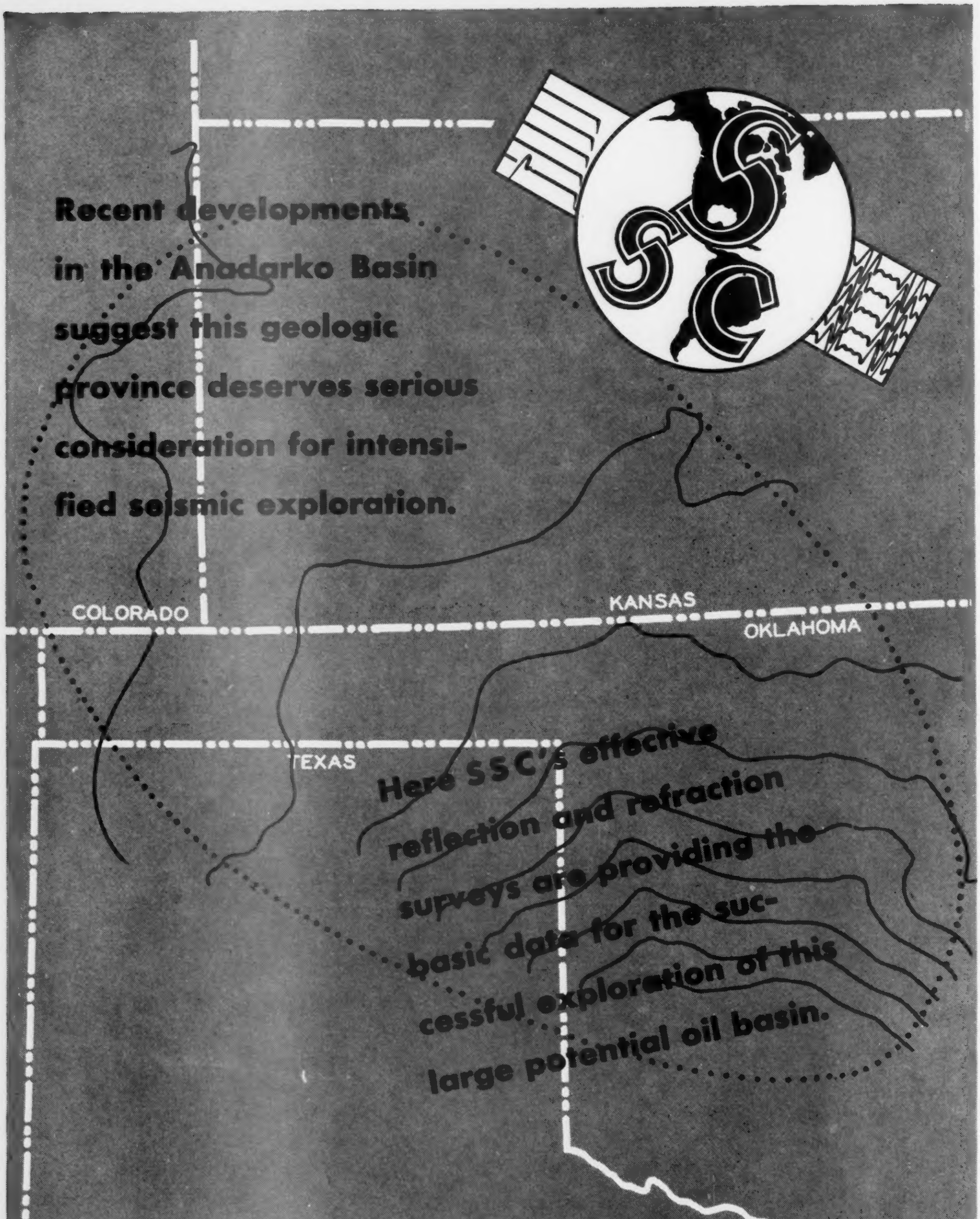

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of the

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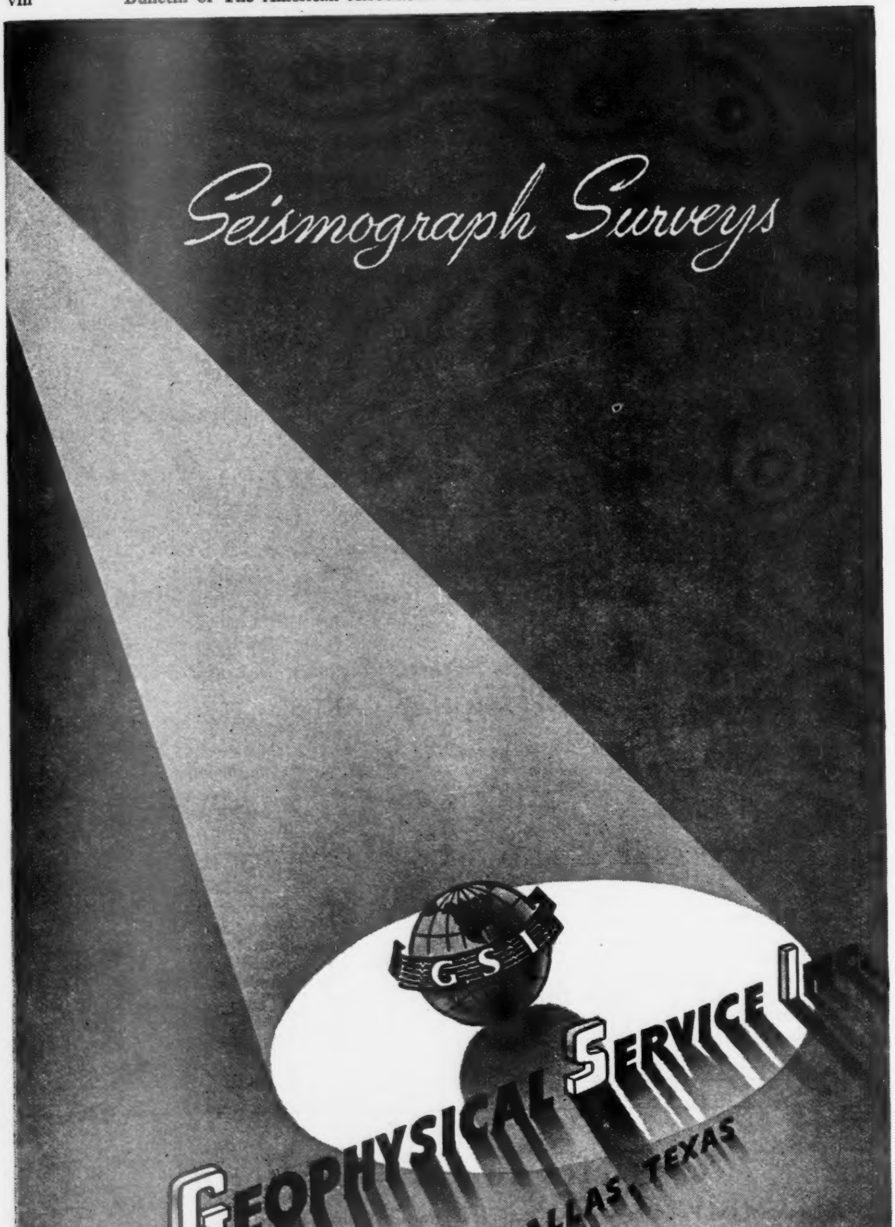
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BULLETIN
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APRIL, 1947

PETROLEUM ON CONTINENTAL SHELVES*

WALLACE E. PRATT†
Frijole, Culberson County, Texas

President Truman on September 28, 1945, issued an Executive Proclamation[1] and an Executive Order.[2] He proclaimed: "The Government of the United States regards the natural resources of the subsoil and sea bed of the continental shelf beneath the high seas but contiguous to the coasts of the United States as sppertaining to the United States subject to its jurisdiction and control." And aimultaneously he ordered: "that the natural resources of the subsoil and sea bed of the continental shelf . . . be and they are hereby reserved, set aside, and placed under the jurisdiction and control of the Secretary of the Interior, pending the enactment of legislation in regard thereto."

In comment on the President's decree, the press quoted a statement by the Secretary of the Interior, Mr. Ickes, that the vital importance to the nation of the potential petroleum resources beneath the continental shelves had led him, months earlier, to recommend to the President the action he had just taken. Another spokesman for the Department of Interior was also quoted to the effect that the exploration of the continental shelves for petroleum and other resourcs would be reserved to the Federal Government itself. The area was so large that years would be required merely to explore it, the spokesman felt, and private industry was not adequate to the task.

Let us review our knowledge of the continental shelves of the earth in the light of our past experience in the search for petroleum, to ascertain what basis this store of knowledge may constitute for the belief that underlying the continental shelves great petroleum resources may be encountered.

If there were no continent of Antarctica, we might speak of the continental

* An address in the 1946 Distinguished Lecture series of the American Association of Petroleum Geologists. Manuscript received, January 8, 1947.

† Geologist.

[1] *Executive Proclamation No. 2667.*

[2] *Executive Order No. 9633.*

shelf of the earth in the singular. All the other continents lie within the confines of a single encircling belt of shallow water which is essentially continuous—the continental shelf. But Antarctica has its own individual continental shelf which it shares with no other continent. Hundreds of miles of oceanic depths must be traversed to reach Antarctica, whatever the line of approach.

The continental shelf is the sea floor beneath the belt of marginal, shallow waters which surround the continents. The usual definition states that the shelf is "arbitrarily" limited to a depth not exceeding 100 fathoms, or 600 feet. It is worthwhile to realize that this limitation to a depth not greater than 600 feet is not in fact "arbitrary," but is wholly logical. We should bear in mind that all the continental platforms are perched on high, steep-sided earth ridges. The present volume of the deep oceanic basins is such that their waters entirely cover the sides of these ridges and rise above them to submerge the outer part of the flat continental margins. The submerged part of the continental margin is the continental shelf.

The continental shelf may be looked upon as part of a larger earth feature; it is the outer, or seaward portion of a great shelving plain which intervenes in the region of the margins of the continents between the continental heights and the oceanic depths. The inland, upper edge of this plain, at an elevation of about 600 feet above sea-level, marks the mean level of the land-and-water surface of the globe; its lower edge, at an elevation of about 600 feet below sea-level, marks the brink of the steep continental slope, which descends into the deep oceanic basins proper. Its outer edge also marks the depth limit of effective wave and current action on the sea floor and the limit to which sunlight is able to penetrate below the surface of marine waters.

This great marginal plain, the outer part of which is covered by marine waters, comprises about 10 per cent of the entire surface of the earth. Beneath the inland half of this plain are situated the natural reservoirs from which has come the bulk of all the petroleum the world has consumed in the past, together with those which contain an even larger proportion of our proved petroleum reserves. The question we now ask ourselves is, what are the prospects for petroleum under the adjacent submerged portion of this plain.

The aggregate area of the continental shelves is roughly 11 million square miles.[3] Of this total area, about one million square miles is contiguous to the coasts of the United States, including Alaska. Among the continents, Africa exhibits the least expanse of continental shelf. The eastern margins of North and South America have wide continental shelves, whereas their western coasts plunge with relative abruptness to oceanic depths. Similarly, the eastern edges of the continents of Asia and Australia, together with the intervening region of the East Indies, are bathed by wide stretches of shallow, continental-shelf water.

But the great Mediterranean regions of the earth, as would be anticipated from their character as land-locked seas, are marked by the most conspicuous

[3] E. Kosinna, "Die Erdoberfläche," *Handbuch Geoph.*, Vol. 2 (1933).

development of continental shelves. The Arctic Mediterranean, commonly designated as the Arctic Ocean, but in reality a shallow land-locked sea occupying the depression bounded by the continents of North America, Europe and Asia; the American Mediterranean, the waters of the Gulf of Mexico and the Caribbean Sea in the irregularly downwarped basin between the continents of North and South America; the Asiatic Mediterranean, the island-studded and essentially land-locked seas lying between the continents of Asia and Australia; and the mediterranean region of Europe and the Near and Middle East; within these four regions there is developed more than 50 per cent of the total continental-shelf area of the earth.

The further reflection should be recorded in this connection that three of the great mediterranean regions of the earth have already become major sources of petroleum; and the fourth, the Arctic Mediterranean, still largely unexplored, manifests impressive surface evidences of petroleum.

There are also portions of the continental shelves outside of the mediterranean regions of the earth which appear to bear a significant relationship to petroleum resources on land. Even the relatively narrow continental shelf of the western coasts of the Americas expands locally and takes on important proportions in the vicinity of existing oil fields, as, for example, in the region of the Los Angeles Basin in Southern California. Viewed from the adjacent continental shelf the Los Angeles Basin becomes only one lobe of a larger basin, much of which is submerged beneath continental-shelf waters.

We can discern something of the character of the continental shelves if we glance at the theories of origin which attempt to account for them. It is obvious that these fringing terraces, encircling the continents, are in part built up of the débris of soil and rock fragments weathered and eroded from the surface of the adjacent land, and carried into the sea by flowing water, and by wind. In part, again, they consist of the residue of marine organisms and the chemical precipitates which sink to the bottom and are buried upon the floor of the sea. This blanket of sediments is in general very thick but in regions of a stable earth crust where there has been no foundering of the continental margins, the original material of the pre-Cambrian continents may itself constitute the surface of the shelf. And in regions of recent or limited foundering the former land surface may now merely be submerged without any cover of new sediments.

Nansen,[4] the Norwegian zoologist whose Arctic explorations made him famous a generation ago, was a pioneer in the study of the continental shelf. He concluded that the landward portion of the Arctic shelf had been planed off by tides and currents to become a surface of marine abrasion, while the seaward portion is built up by the accumulation of the material swept out toward the continental slope by the same forces. He perceived also that on the inner, abraded portion of the shelf little deposition of sediments takes place, except in local downwarps or

[4] F. Nansen, quoted by R. N. Rudmose Brown, *The Polar Regions*, pp. 67–71. Methuen and Company, Ltd., London (1927).

depressions. The general surface of the shelf became for Nansen, as it is for us to-day, at once, a "base level" of erosion and a "top level" of deposition. Nansen concluded also that the continental shelf is a mobile segment of the earth's crust. The deposition of the sediments, he thought, tends to press it down. This depression of the sea floor, Nansen suggested, is compensated by an upheaval of the adjacent land, a tendency which is stimulated by the accompanying removal of the load on the land through erosion. It will be apparent from these ideas that Nansen attached more importance than we now do to the deposition of sediments as a cause of subsidence. He did not realize that usually subsidence and uplift are not the results, but rather the causes of vigorous and extensive deposition.

Nevertheless, Nansen's early views anticipate in some degree modern concepts of continental shelf origin, as elaborated by Umbgrove.[5] Umbgrove recognizes the planation of the landward portion of the continental shelf. He believes it to have been accomplished largely in Pleistocene time when sea-level stood some 100 meters lower than at present. The outer portion of the shelf, Umbgrove accounts for, by spasmodic warping or tilting movements along the continental border. These movements are caused by periodic, deep-seated convection currents of magma arising from the earth's fluid interior along the zone of contact of the light material of the continental eminences with the heavy material which makes up the ocean floor. The gravity profiles of Vening[6] Meinesz across the continental margins reveal this zone of transition from the light-weight substance of the continents to the heavier substance of the ocean floor. Vening Meinesz places the contact between these two classes of crustal materials along the continental slope at the outer edge of the continental shelf. Like Nansen, Umbgrove believes that the periodic submergence in the region of the continental shelves of what has been the margin of the continent is compensated by a simultaneous bowing up of a new marginal tract adjacent and parallel to the newly formed coast line.

Thus the region of the continental shelf takes on the character of an extremely mobile segment of the earth's crust. Dramatic evidence of the active sinking tendency of the continental-shelf regions is the presence of profound deeps immediately adjacent to the shelf area. The lowest part of the ocean floor is the Philippine Deep at the very foot of the continental slope of eastern Asia. Other similar deeps border the continental shelves quite commonly over the earth.

To emphasize the scope of the movements he describes along the margins of the continents, Umbgrove cites the results of seismic surveys by Ewing and others[7] across the continental shelf flanking the Atlantic coast of the United States. These surveys revealed, at a point only 60 miles seaward from the present

[5] J. H. F. Umbgrove, "Origin of the Continental Shelves," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 30, No. 2 (February, 1946), pp. 249–53.

[6] F. A. Vening Meinesz, "Gravity over the Continental Edges," *Proc. Kon. Akad. van Wetensch*, Amsterdam, 44 (1941).

[7] M. Ewing, A. P. Crary, H. N. Rutherford, and B. L. Miller, "Geophysical Investigations in the Emerged and Submerged Atlantic Coastal Plain," *Bull. Geol. Soc. America*, Vol. 48 (1937).

coast line, a prism of sediments some 12,000 feet in thickness. These sediments are believed to have accumulated since the beginning of the Triassic on top of the earlier surface of the edge of the continent as it became more and more deeply submerged. Yet our Atlantic seaboard, where this remarkable downwarping has taken place, is considered to be a relatively stable segment of the continental shelf.

Modern investigations have also confirmed Nansen's pioneer observation that the inland portion of the continental shelf is a surface of degradation. Unless the shelf sinks below the base level of wave action, but little sediment remains upon it. Studies by Emery and Shepard[8] off-shore from Southern California prove that only coarse sediments and indurated rocks, similar lithologically to those of the bordering land area, are to be found on the general surface of the shelf, and that deposition of fine-grained sediments is currently in progress only in closed basins and troughs, depressed below the general level of the shelf.

In addition to its extreme mobility, then, the continental shelf constitutes an automatically functioning mechanism for classifying and segregating sediments according to their grain-size. Coarse materials, winnowed of muds and silts, are left on the higher surface of the shelf, at the general base level of erosion, where they come to form eminences on the sea floor. Frequently these heaps or bars of coarse-grained sediments mark positive elements in the mobile zone of the continental shelf. On them as a foundation, reef-building organisms commonly erect their structures. The muds and silts, in turn, flushed out of the sands and gravels, are swept into the low portions of the shelf surface or are borne on out to come to rest finally on the continental slope. The fine-grained sediments tend especially to settle into closed basins, downwarped below the general surface of the continental shelf. Thus we have in the continental shelf a surface on which the eminences tend to consist of porous coarse-grained sediments and reef structures, whereas the surrounding depressions are filled with muds. While the two classes of sediments are well classified and separated, interfingering wedges of each penetrate the other. These features of continental-shelf structure range in size from local sand bars and coral reefs interspersed among minor, shallow depressions, to great submarine platforms adjacent to profound deeps.

Before we inquire specifically into the nature of the continental shelves as an environment suitable for the occurrence of petroleum, it will serve our purpose to review the conditions we believe to be essential to the origin and accumulation of petroleum.

We shall fail to comprehend the nature of petroleum occurrence until we realize that the generation of petroleum is an inevitable concomitant of fundamental earth processes which have been operative ever since the end of the pre-Cambrian. Geologists and geographers alike have proposed that the earth should be viewed as a single functioning organism. One of the normal functions of the

[8] K. O. Emery and F. P. Shepard, "Lithology of the Sea Floor Off Southern California," *Bull. Geol. Soc. America*, Vol. 56, No. 4 (April, 1945), pp. 431–78.

earth, so viewed, ever since life came to cover its surface, appears to have been the generation of petroleum.

Illing[9] epitomizes this conception that petroleum is a common by-product of a normally functioning earth. He speaks of "oil in the sedimentary cycle":

> Oil is something which is born in a cycle of sedimentation. When and how it is born is not quite clear, but it is not due to abnormal, accessory circumstances, such as igneous activity. Furthermore, and here perhaps the thesis is not so widely accepted, petroleum is a natural and common substance in a sedimentary cycle. It is not some freak material, requiring for its formation peculiar and unusual physical conditions. That it requires certain definite conditions is undoubted, but the more the extent of petroleum occurrence is studied, the firmer is the conviction that petroleum source-rocks, i.e., the mother rocks from which the oil is produced, are formed in environments which occur quite commonly, and particularly in a cycle of marine deposition on the continental shelf.

The accepted conditions for petroleum generation are stated clearly by van der Gracht:[10]

> [My] own view, arrived at after consideration of world-wide research on modern marine sediments, . . . [is] that commercially important accumulations of petroleum belong exclusively to two related classes of sediments: (1) those of the more or less euxinic facies, typically present in the Black Sea, which has clearly occurred locally throughout geologic time, and (2) sediments of a moderately saline facies, where the sea bottom was covered by water of a strong saline concentration. Both facies have this in common: organic life (which may be exceptionally prolific under these circumstances) is confined to the upper horizons of more normal water, whilst the deeper and notably the bottom layers of water are devoid of oxygen and in the extreme phase, contain poisonous admixtures which exclude life on the bottom (benthos). In consequence, all organic sediment (chiefly derived from plankton) is preserved from attack by the numerous scavengers which abound on all normal sea bottoms, and becomes fossilized.

The conditions which control the accumulation of petroleum, van der Gracht summarizes as follows:[11]

> [Commercial oil fields] occur preferably in two distinct structural provinces: (1) the foredeeps of the folded mountain belts and (2) on mobile Epi-continental shelf regions.

The organic life of saline waters, which van der Gracht and others generally believe to be the source material of petroleum, is concentrated in that relatively small fraction of these waters which overlaps the continental shelves. Lohman[12] is convinced that coastal waters, on the whole, are fifty times more productive of life than the open sea. Trask's[13] comprehensive studies of organic matter in recent sediments reveal an average organic content of 2.5 per cent for terrigenous (near

[9] Vincent C. Illing, "Geology Applied to Petroleum," *Oil Weekly* (July 15, 1946), pp. 34 *et seq.*,

[10] W. A. J. M. van Waterschoot van der Gracht," The Statigraphical Distribution of Petroleum," *The Science of Petroleum*, Vol. 1, p. 58. Oxford University Press, London (1938).

[11] *Idem*, "The Geographical Distribution of Petroleum," *ibid.*, p. 63.

[12] H. Lohman, quoted by H. V. Sverdrup, Martin W. Johnson, and Richard H. Fleming, *The Oceans*, p. 763. Prentice Hall, Inc., New York (1942).

[13] Parker D. Trask, *U. S. Geol. Survey Prof. Paper 186H* (1937).

shore) sediments, only 1 per cent for abyssal (deep sea) sediments. The sediments of the continental shelf, Trask found, generally run from 2 to 3 per cent of organic matter but higher values, from 5 to 10per cent, prevail in the fine-grained sediments deposited in local downwarps in the shelf surface and on the continental slope.

The primary source of food for all marine life is plankton, the microscopic plants which abound in surfa-e waters. These tiny plants, utilizing the energy of sunlight, render the inorganic salts of the sea into food for themselves and in turn for all the higher animal life of the sea. Plankton consists of simple organisms, common in the earliest seas in which petroleum formed; seas in which higher forms of life were perhaps too sparsely developed to supply enough organic matter for great oil fields. Consequently, it is believed that plankton itself may be an important source material of petroleum.

It has been observed that plankton thrive where upwelling waters bring to the surface the inorganic plant nutrients, such as nitrates and phosphates, which normally tend to accumulate on the sea floor beyond the reach of the surface-dwelling plankton. This relationship is illustrated by the remarkable girdle of diatom remains which encircles the earth off the coasts of Antarctica. Covering the floor of the sea this broad belt of plankton residue marks the zone throughout which the convergence of tropical and polar waters brings about an upwelling of deep-seated currents. This zone is replete with marine life. It is the feeding place of the myriads of sea birds whose droppings form the extensive beds of guano which mantle numerous islands in the South Pacific. In the waters of this zone, also, the great whales of commerce graze.

Trask[14] explains the abundance of life on the continental shelves also, in part, by the upwelling of bottom waters along the steep wall of the continental slope at the outer edge of the shelf. Thus the configuration of the sea floor, always important to petroleum generation, acquires even greater significance.

Heald[15] reminds us that only the fine-grained sediments are rich in organic material.

> Circumstantial evidence from thousands of oil fields indicates overwhelmingly that the petroleum originates in sediments and careful research has convinced geologists that only shales and limestones need be considered as possible source beds . . . shales and limestones that originally were muds under saline water.

We have already observed that these fine-grained sediments of which Heald speaks—the muds and the oozes—come to rest on the sea floor only where they sink below the limit of wave-and-current action, that is, to depths exceeding 600 feet. Therefore, they do not remain on the general surface of the continental shelf, but either they are swept into the stagnant waters filling closed basins depressed below the general surface of the shelf, or they are borne on out to the

[14] *Idem*, "Organic Matter in Recent Sediments," *Problems of Petroleum Geology*, Amer. Assoc. Petrol. Geol. (1934).

[15] K. C. Heald, "Essentials for Oil Pools," *Elements of the Petroleum Industry*, Amer. Inst. Min. Met. Eng. (1940), p. 26.

continental slope. In closed basins, because of the greater salinity and consequent higher gravity of the lower stagnant layers and the resulting absence of normal convection currents, little or no oxygen is carried to the bottom. Without oxygen, the scavengers which in open water consume the organic matter of the sea bottom, cannot survive and so the organic débris accumulating in the closed stagnant basins is preserved.

That the organic sediments which escape entrapment in the downwarps of the continental shelf are not entirely consumed by scavengers, but do finally rain down on the continental slope, is evidenced by the fact already noted, that on the continental slope Trask found sediments richer in organic matter than any others except those taken from the floors of stagnant basins. It is also veident that this organic material does not accumulate on the floor of the oceanic basins proper since there Trask found only small admixtures of organic matter.

Weeks[16] has observed that the great oil fields of the earth occur in the region of the deep basins or downwarps of the major mobile segments of the crustal envelope. These mobile segments, in turn, particularly in Mesozoic and later times, Weeks notes, have marked the peripheries of the continents. With the close of the Paleozoic and the beginning of Mesozoic time, there appears to have been a marked subsidence or foundering of the marginal parts of the continental platforms and a development of new zones of mobility. These movements were pronounced in the great mediterranean regions of the earth, and the stimulus they gave to erosion and sedimentation persists even today. In the wedge of sediments which makes up the continental shelves, therefore, the younger rocks, those of Mesozoic and later ages, must be present in larger proportion than on the continental platforms.

Weeks has determined also that the incidence of oil occurrence, measured in commercial fields per unit of volume of sediments and per unit of time diminishes as we move toward the stable, interior portions of the continental platforms. The continental platforms were submerged beneath ocean waters more widely in Paleozoic time than at any subsequent period. During this extensive submergence notably mobile belts, marked by profound downwarps, traversed regions now well within the interior of the continents. As a result we have the great foredeep along the eastern margin of the Rocky Mountains across the entire length of North America and a similar feature along the Andean front in South America. We have also other great basins, such as the Anadarko basin in Oklahoma, and we have similar great Paleozoic downwarps on other continents. Nevertheless, a large proportion of Paleozoic sediments were deposited in shallow interior basins on the forelands of the stable continental platforms, where sedimentation was slow and marine life not too abundant. And while, by dint of intensive exploration, we have produced a great deal of oil from these shallow interior basins in the

[16] L. G. Weeks, "Basins and Oil Occurrence," Unpublished report to the Standard Oil Company (New Jersey), New York.

United States, yet the oil fields in them are rarely large and their unit yield is generally low.

Weeks reminds us also that the more closely we approach to the recent in geologic time, the more abundantly do we find oil. Indeed, the index of oil occurrence per unit volume of sediments, and per unit of time, reaches a maximum in the Pliocene, the youngest of the Cenozoic sediments. In this connection, it is of interest to speculate on the possibility of oil resources in the Pleistocene rocks which were laid down following the close of the Pliocene. In consequence of the recession of the seas of the outer margins of the continental platforms during Pleistocene time, sediments of Pleistocene age must be present in greater volume on the continental shelf and slope than on the present land. It is true that some of us have concluded that Pleistocene rocks are too young to contain oil in commercially valuable accumulations. One of the firm "posts" in the "geologic fence" which Cox[17] has thoughtfully constructed to keep all of us within the confines of demonstrated fact in our zeal to push back the frontiers of our knowledge of petroleum occurrence, is the minimum time requirement for petroleum genesis. Cox places this minimum at one million years. He anchors this post in his geologic fence in the fact that no oil of indigenous origin has ever been recovered from Pleistocene rocks, the oldest of which were laid down about one million years ago.

Nevertheless, an impressive array of data supports the conclusion that the accumulation of petroleum is often completed soon after the source rocks are deposited. May it not be that the limited occurrences of Pleistocene sediments on the continental platform to which our past search for oil in the Pleistocene has been confined, are a less suitable facies than the more largely marine Pleistocene beds which we would reasonably expect to encounter in the region of the continental shelf? Consider our experience in Texas where, after having failed utterly to find petroleum in wells drilled entirely through the inland portions of sedimentary wedges of Eocene, Oligocene, and Miocene age, respectively, we subsequently discovered that everyone of these units housed large accumulations of petroleum in their seaward extensions. We only learned this from wells drilled later at locations a hundred miles, or so, nearer to the present coastline. May we not hope for a like surprise on the continental shelf if we ever come to explore there the seaward extension of the Pleistocene sediments?

In summary, then, the conditions we believe to be favorable to the generation of large volumes of petroleum include an abundance of organic material along with an abundance of sediments, all deposited rapidly in saline waters in an environment which excludes both the process of oxidation and the normal scavengers of the sea floor. This environment usually prevails in the stagnant waters which fill the sharp downwarps in the sea floor in mobile segments of the earth's

[17] Ben B. Cox, "Transformation of Organic Material into Petroleum under Geological Conditions (The Geological Fence)," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 30, No. 5 (May, 1946), p. 645.

crust. And the conditions we believe to be most favorable to the accumulation and preservation of large volumes of petroleum in natural reservoirs underground, include the presence of sealed lenses or bars of mud-free, porous sands, or limestone reefs, adjacent to large volumes of organic saline muds, the fluids from which can move freely into these porous rocks under the growing pressures of progressive compaction.

By way of fulfilling these conditions, we have in the continental shelves a highly mobile segment of the earth's crust, the periodic downwarping of which depresses it below sea level, accentuates erosion and multiplies the rate of deposition. In this mobile zone of rapid sedimentation bordering the continental platforms, there has accumulated a thick wedge of sediments. Along the adjacent steep continental slope, upwelling currents, laden with plant food, stimulate marine life to unparalleled abundance. Sweeping across the sea floor, other currents and waves separate fine sediments from coarse, build the latter into bars of mud-free sands and carry away the fine sediments and organic residues to drop them into closed, stagnant basins, where little or no bottom life survives and where a uniformly reducing environment prevents oxidation. Thus, the continental shelf tends to become a great complex of discontinuous natural reservoirs which grades seaward, with much interfingering of sand lenses and layers of fine-grained sediments, with frequent overlaps, diastems and unconformities, into the rich organic muds of the continental slope. And laterally as well as seaward, these reservoir beds merge gradually with the organic sediments that have filled the deep, stagnant basins, characteristically downwarped in the surface of the continental shelf and slope. Under these conditions there is maximum opportunity for fluids, squeezed out of the muds and oozes as compaction proceeds, to move into the adjacent reservoir beds.

By way of further summary we may note that several factors stamp the peripheries of the continents as a fundamentally superior environment for the generation and accumulation of petroleum. Among these factors is the coincidence of the shelf region geographically with the contact zone between the low-specific-gravity rocks of the continental platforms and the heavy rocks of the ocean floor on which the continents float. This contact zone is the locus of most of the earth movements which adjust and compensate by thrust, subsidence, and uplift the stresses built up in the earth's crust. As a result of these movements we have the sharp downwarps of the sea floor and the accompanying rapid sedimentation which combine so effectively to entomb and preserve from oxidation organic residues from which petroleum may be generated. The shelf region also coincides geographically with the most extensive development of sedimentary beds of Mesozoic and Cenozoic age—beds which house much the larger part of the petroleum so far discovered on earth. Another favorable aspect of the region of the continental shelf is the concentration of marine life and the resulting wealth of organic residue in the waters overlying the continental slopes. This concentration of life is accentuated by the upward deflection of ocean currents impinging

on these steep slopes and the consequent overturning and upwelling of bottom waters laden with the inorganic plant nutrients upon which, in the final analysis, all marine life is sustained. Shallow interior seas lack this source of plant food and may be correspondingly poorer in organic matter. Still another favorable factor is the inherent tendency of continental shelf processes efficiently to classify coarse and fine sediments, to segregate the coarse sediments on the highs and to sweep the fine sediments into the adjacent downwarps of the shelf surface.

Altogether we may fairly conclude that if Mother Earth, a long time ago, had been wise enough to foresee that in the distant future she would come to give shelter and sustenance to human children who would have imperative need for great volumes of petroleum, and if she had immediately set about to devise an effective mechanism within the framework of the forces and materials at her command, for the purpose of generating and conserving stores of petroleum adequate to meet this future need, she could scarcely have hit upon a more efficient agency than the continental shelves.

Our search for petroleum on earth has been confined almost entirely, so far, to the sediments deposited in former seas which spread periodically over the present land areas during periods of temporary submergence. Twenhofel,[18] whose researches have led his fellows to bestow upon him the fitting title of "father of sedimentation," has estimated the total area of these sediments at 45 million square miles and their volume at 45 million cubic miles; that is to say, their average thickness is only one mile. But only about 80 per cent of these rocks, according to him, are of marine origin. The rest were laid down in fresh or brackish water and are therefore not promising source rocks for petroleum. Moreover, a large proportion of the sediments deposited on the present land areas has been so metamorphosed by the orogenies that have brought to an end each of the diastropic cycles in the past, as no longer to retain whatever petroleum may formerly have been present in them. Taking into account this factor, Weeks[19] has estimated the total area of the possibly oil-bearing sediments on the land surface of the earth at no more than 15 million square miles, and their volume at only 20 million cubic miles.

In comparison with the extent of the marine sediments remaining on the continents, Twenhofel has estimated the area of the sediments on the continental shelves of the earth at 10 million square miles, and their volume at 30 million cubic miles; their average thickness, then, he places at 3 miles. But we must take account also in this connection of the continental slope on which the fine organic sediments that sweep out to sea across the general surface of the continental shelf finally come to rest. The area of the continental-slope sediments, Twenhofel estimates at 15 million square miles, and their volume at 40–50 million cubic miles, or more.

[18] W. H. Twenhofel, *Treatise on Sedimentation*, pp. 860 *et seq.* Williams and Williams Company (1932).

[19] L. G. Weeks, *op. cit.*

Altogether then, in or adjacent to the continental shelf we have a total volume of 70–80 million cubic miles of sediments. Some part of this volume, however, like the sediments of the present land surface, has been metamorphosed and rendered unpromising for petroleum, although, because of the probably younger average age of the shelf sediments, their metamorphism must be less complete than is true of the sediments of the present land surface. Perhaps we shall make a sufficient allowance for metamorphism if we reduce the foregoing total to 50–60 million cubic miles.

In comparison with some of her sister planets, our earth appears to have set out in life with only a niggardly endowment of hydrocarbons. Astronomers assure us that the great planets, Jupiter and Saturn, in their intensely cold and presumably lifeless realms of outer space, are bathed by oceans of liquid methane, our most common hydrocarbon. Even Saturn's moon, Titan, is wholly enveloped in a shroud of methane. Moreover, the fall of meteorites brought home to us long ago the amazing fact that among the compounds and elements which make up these celestial wanderers—the very stuff of the inorganic world—hydrocarbons are present. Why, then, is our own planet obliged to go about it "the hard way" and produce our petroleum from organic material? Where is our own heritage of the hydrocarbons displayed in such abundance elsewhere in the solar system?

The answer is, of course, that the juvenile earth, relatively small and hot, was unable to hold her primordial atmosphere, and so lost any original store of hydrogen which might later have combined with carbon to form hydrocarbons. The outer planets, with greater masses and lower temperatures, were able to retain their original gaseous constituents. But the present atmosphere of our planet is of secondary derivation. The nitrogen, argon and carbon dioxide in it are exhalations from deep within the earth through volcanoes. Volcanoes, however, give off no oxygen, and there appears to have been little or no oxygen in the atmosphere of pre-Cambrian time.[20] Whence then came the oxygen which makes up so large a part of our present atmosphere?

The agency which added this oxygen is, of course, the plant life of the earth, and the source of the oxygen is carbon dioxide which, along with water vapor, made up most of the earliest atmosphere the growing bulk of the earth finally enabled it to retain. The present oxygen content of the atmosphere, then, has been built up by green planets at the expense of the earth's original store of carbon dioxide. But the point of immediate interest is that for every atom of oxygen released to the atmosphere another atom of carbon is incorporated by the plants into organic material. When this organic material later decays, of course, it recombines with oxygen to form carbon dioxide again and the cycle starts all over anew. But whenever organic matter is buried in marine sediments so as to escape oxidation, there is a net gain in free oxygen.

So it is that the excess of oxygen evolved by planets from carbon dioxide over

[20] W. H. Twenhofel, *op. cit.*, p. 290.

that reclaimed by the oxidation of organic matter, becomes a measure of the amount of organic matter preserved in the sedimentary rocks.

The free oxygen of the atmosphere, however, represents only a fraction of the total oxygen released by this entombment of organic matter. There is to be added the "fossil oxygen" claimed by the weathering processes and withdrawn from the atmosphere to be locked up in the oxidized mantle of rocks and soils. Jones[21] estimates the present amount of this fossil oxygen at double that of the atmospheric oxygen, which, in turn, he places at more than 11,000 billion tons. Thus the total weight of the oxygen released by plant life from carbon now buried in the organic matter of the sedimentary rocks becomes approximately 34,000 billion tons. The weight of the organic matter itself, in which this carbon is included, would be about 60,000 billion tons.

These astronomical figures serve only to reveal that the amount of organic material entombed in the sedimentary rocks of the earth is veritably "large beyond computation." They do not tell us, and we are not able to determine what part of this total amount of organic material has actually been converted into petroleum through the ages. Even if we could determine how much petroleum had actually been formed in the first place, we would still have no clue as to what proportion of the petroleum originally formed may have accumulated and been preserved intact in natural reservoirs underground.

To gauge the approximate volume of the potential petroleum resources of the continental shelves, our best criterion is our long experience in oil-finding on the adjacent land areas. Within the United States we have been engaged for more than three quarters of a century in the exploration of sedimentary rocks exceeding 1.5 million square miles in area, with a volume of from 2.5 million to 3.0 million cubic miles. In this exploration, which is still not complete, we have already discovered some 53 billion barrels of oil. No one doubts that large additional volumes of oil await future discovery. The area and volume of the sedimentary rocks we have explored in this country constitute some ten per cent of the total which Weeks' estimates allot to the sediments remaining on the entire land surface of the earth in which oil may reasonably be expected to occur. This volume of sediments is large enough to be representative and to make our experience in exploring it representative for the land surface of the earth. If it is also representative for the sediments of the continental shelf and slope, then the estimated 50–60 million cubic miles of these sediments should contain about 20 times as much oil as the sediments we have been engaged in exploring in the United States.

On the basis of our past discoveries in the United States, then, the region of the continental shelves of the earth should contain more than 1,000 billion barrels of oil or approximately 500 times the world's present annual consumption. If, in the future, we find additional stores of oil within the land area of the United

[21] H. Spencer Jones, *Life of Other Worlds*, pp. 91 and 113. The Macmillan Company (1940).

States, or if the sediments of the continental shelf and slope are inherently better suited to petroleum occurrence than those within the land area of the United States, then the total for the region of the continental shelves should be correspondingly greater.

That normal earth processes make probable large volumes of petroleum beneath the continental shelves is a comforting reflection to geologists who feel the responsibility of assuring the nation adequate supplies of liquid fuels. For them, the potential petroleum resources of the continental shelf constitute the proverbial "anchor to windward." There these resources should be whenever we need them badly enough to go after them in earnest. But this possible increment to our petroleum resources, overwhelming in its proportions though it may be, is as yet only of remote interest. It is of no special significance to us as long as we can supply our needs for liquid fuels at lower costs from other sources.

To Zimmerman,[22] such natural resources as petroleum and coal are, in themselves, mere "neutral stuff," a term he borrows from the language of philosophy. Natural resources can only function, Zimmerman says, in combination with two other resources, namely, human resources, by which he means knowledge, effort and achievement; and cultural resources, such as tools, spectacles, irrigation systems, and railroads. But cultural resources include also those social institutions which promote cooperation between individuals and groups. Governments themselves are cultural resources.

Zimmerman reminds us that government as a cultural resource, can facilitate greatly the development of natural resources. But the reverse is also true; unwise government policy may impede utilization of natural resources. The American government is an example of a cultural resource which has so functioned in the past as greatly to stimulate the development of natural resources, but other governments may readily be called to mind which, by restrictive laws and policies, have denied their citizens the stimulating effect of a cultural resource without which it has proved impossible for them to develop their natural resources. And if the American government adheres to the policy announced by the spokesman for the Department of the Interior, reserving to itself the right to explore for petroleum on the continental shelves and denying to private enterprise any similar right, then it will have withheld from its citizenry a cultural resource which is essential to their most effective cooperation. In exploration for petroleum no single agency, not even the government, can succeed as well or as rapidly as the multiplicity of aggressive, independently operating agencies which comprise the American oil-producing industry.

As a matter of fact, the President's executive order has already created uncertainty. More than one state has already declared its ownership and control of the waters extending out to sea far beyond the conventional 3-mile

[22] Erich W. Zimmerman, "Resources—an Evolving Concept," *Texas Acad. Sci.* (Dallas, September, 1945).

limit. Ours is "an indissoluble union of indestructible states." As Borchard[23] has pointed out, when in the past the United States has acquired new territory within the present continental limits, the acquisition has been only for the purpose of creating new states, and in such acquisitions title to the bed of the adjacent sea has always passed to the abutting state when that state was admitted to the union. If this doctrine were still valid, the effect of the President's recent proclamation would be simply to extend the boundary lines of the abutting states out to the limits of the continental shelf. No part of the open sea overlying the continental shelf could conceivably be erected into a new state and so, if the United States extends its boundaries seaward, that action would automatically extend seaward the boundaries of the abutting states to include the territory newly acquired.

If this were the effect of the President's proclamation then the continental shelves would come under the jurisdiction of the several abutting states, not the Department of the Interior, and the right to explore the natural resources of the continental shelf would come to be administered by the individual abutting states, not by the federal government.

We are, of course, already engaged in a preliminary way in exploiting the petroleum resources of the continental shelves. Off the coasts of Texas, Louisiana, Florida, and California, extensive geophysical surveys have been carried out and numerous wells have already been drilled into continental shelf sediments under legal authority granted by the officials of the abutting states. Petroleum is already being produced under state authority from the continental shelf adjacent to California, Texas, and Louisiana. In our search for oil on the land, our operations have brought us, in one region after another, all over the earth, to the seacoast. Although it is perfectly clear to us that petroleum resources do not stop at the water's edge we have not yet really undertaken to push our pursuit of them out to sea.

Perhaps we would be able to visualize more clearly the problem of recovering the petroleum resources which appear to be present beneath the continental shelves of the earth if we first eradicated from our minds the fixed idea that oil is something which comes from oil wells. This unconscious obsession clouds our vision. If we were able to see clearly through the maze of derricks to which we have conditioned our normal vision, we might discover that the most practical approach to great stores of petroleum in the sediments of the continental shelves, once we have proved their existence, is not through the waters of the turbulent sea above them, but along the sea floor beneath these waters; not through a multitude of wells drilled through ocean waters (if wells can be drilled through waters), but through a few galleries constructed upon or excavated into the ocean floor from the adjacent land. Into these galleries, hundreds of miles in

[23] Edwin F. Burchard, "Appendix B," *Rept. Senate Judiciary Committee on H. J. Res. 225.*

aggregate length, perhaps, oil would drain from a score of natural reservoirs distributed along their course, through wells drilled downward and outward in appropriate directions; and through suitable pipelines, traversing these galleries, the oil would then flow landward.

The art of excavating, maintaining, draining and ventilating extensive tunnels and shafts in the rocks of the earth's crust is already highly developed; it is as old as the history of man and it has been stimulated immensely in modern time. World War II has virtually driven us underground. The advent of the atomic bomb hastens this movement from the surface to the depths of the earth. Not only highways, key-factories and power plants but hospitals and schools as well, are to be located beneath the surface in the future, for safety's sake. It is unlikely in any event that we shall be content to leave our future oil fields above ground—or, should we say, above water. To construct a tunnel a hundred miles long on or beneath the floor of the sea poses no insuperable, or even particularly novel problem to modern engineering. The work would require elaborate mechanization and great skills in design and organization, but these would be forthcoming, granted only that the assured reward had been shown to justify the cost. A nominal charge per barrel on the contents of a half dozen East Texas or Lake Maracaibo oil fields would very soon return the cost of a system of tunnels hundreds of miles in length.

We have already begun to draw upon the petroleum resources of the continental shelves of the earth through the extension of our established land operations out over the water. This extension is the logical development of the present technique of winning petroleum from the earth. Unless these initial operations over the water are stifled by some such action as the announced plan to reserve to government all exploration of the continental shelves, they will gradually quicken their pace and expand their scope until oil from the continental shelf supplies a significant part of our total national consumption. These operations do not, however, promise a comprehensive solution of the problem of recovering the petroleum resources of the continental shelves. That solution will not be forthcoming until the time is at hand when our natural resourcefulness fails longer to contrive a preferable source of liquid fuels. In view of the prospect for almost unlimited energy from sub-atomic forces within the next few decades, and the even more imminent promise of liquid fuels from coal at costs but fractionally higher than the prevailing cost of gasoline distilled from petroleum, this contingency appears to be remote. We may never find ourselves called upon to attempt the recovery of more than the most available fraction of whatever petroleum the continental shelves may house. But if occasion to develop fully the petroleum resources of the continental shelves ever arises, we may rest assured that the technical problems incident to their development will be readily solved under the spur of an adequate incentive.

The petroleum resources of the continental shelves are ours to exploit whenever to exploit them becomes worth while.

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EVOLUTION OF GEOLOGIC THOUGHT IN PROSPECTING FOR OIL AND NATURAL GAS*

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ABSTRACT

Following a brief review of the historical development of oil and gas in the United States until the drilling of the Drake well, the more important opinions that have been expressed concerning the geology of oil and natural gas are presented. These include origin, migration, accumulation, reservoir traps, and their means of recognition. The progress of geologic thinking is traced through the main stages of its development, from the first theories pertaining to oil and gas occurrence, the technical advancements that have been made, and the effect of economic demand upon the employment of geologists by industry, to the present trends in thought and techniques.

Recent geologic thinking has been dominated by the recognition that reservoir traps could exist without dip reversals due to deformation, and could result from a lithologic change, giving a stratigraphic-type reservoir. Specializations in research were required which would give new and sufficient data concerning all phases of sedimentation to permit a reconstruction of depositional environment and deformational history—historical geology under the microscope. Discovery of new areas of production will require the application of existing geologic knowledge and techniques plus new geologic knowledge and techniques, and especially their increased coordination.

HISTORICAL SKETCH

The story of petroleum and natural gas has had its beginnings in much the same manner wherever these resources exist. They have been issuing from the earth for untold ages and certainly must have aroused the curiosity and ingenuity of man ever since he became a reasoning being. Even before recorded history, some form of petroleum was used in the buried cities of Ur, which antedated Babylon, probably as early as 4000 B.C.

References to the occurrence, method of recovery, and uses of petroleum, variously called "pitch," "bitumen," "slime," "asphalt," "tar," and "heavy water," appear in the earliest written records of man's experiences.

The water-repellent properties of pitch were early recognized and the substance was used to render cisterns and silos water-tight. Some of these structures of unknown antiquity are still found intact in the ancient cities of Egypt and Mesopotamia. Similarly, asphalt was used for boat caulking, the most notable example of which was the Ark of Noah, built according to specifications calling for "6 sar of bitumen on the outside and 3 sar on the inside."

Nebuchadnezzar boasted of his great public works—his walls, roads, and palaces built of "brick and bitumen." Other early uses of bitumen were for cementing the bricks of the great mosaic pavements and the beautifully inscribed alabaster slabs used in the temples and palaces of the ancient cities of Nineveh and Babylon.

Although petroleum was obtained only by collecting it from natural seeps, primitive attempts at oil refining developed. Herodotus wrote of a well from

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which three different substances were produced—asphalt, oil, and salt. This first step upward in oil production was probably caused by the fact that naphtha was more highly valued than the solid bitumen, the most fluid varieties being used in lamps, replacing the crude torches of reeds dipped in oil.

One of the most general uses of oil throughout early history was for its medicinal properties, advertised on clay tablets, in stone, and on paper, as a cure, applied internally and externally, for rheumatism, bruises, toothache, headache, burns, tuberculosis, bronchitis, and restoration of hair. The Egyptians added another which has never been successfully repeated—the use of petroleum in mummification.

The references to early use of natural gas are not so numerous, perhaps because of the difficulty of harnessing this more elusive hydrocarbon. But the spectacular and mysterious phenomena of ignited gas was no doubt exploited to the full in religious ceremonies, for the awe-inspiring sight of flames issuing from the earth put the "fear of God" into the hearts of our own hardy pioneers many centuries later.

In the Appalachian region of the New World, the ancient gravel pits near Titusville, Pennsylvania, indicate that the aborigines made some use of petroleum before the white man invaded the region, and it is quite probable that the "burning springs" and outflows of petroleum on the Little and Big Kanawhas, Big Sandy, and other streams of the Alleghenies, had already attracted the attention of the American Indians and that they were making use of them in their own primitive way, long before the first white settlers crossed the mountains.

One of the earliest records of these natural gas vents or "burning springs" is of that near Charleston, West Virginia. General Washington visited this burning spring in 1775, and pre-empted it along with other lands given to him for military services by the State of Virginia, "on account of a bituminous spring, which it contains, and of so inflammable a nature as to burst forth as freely as spirits and is nearly as difficult to extinguish."

As pioneer settlements spread to the west of the Appalachian Valley region, oil springs and seepages, often associated with salt licks, came to the attention of the white man in western New York, western Pennsylvania, eastern and southeastern Ohio, northern and central West Virginia, eastern Kentucky, eastern Tennessee, and northern Alabama.

In those early days, however, interest in the brine springs, or "salt licks," was far greater than in the frequently accompanying oil. Salt licks and salt springs received immediate attention, and when the supply of salt from these became inadequate, pits were dug. The first pits were merely enlargements of the springs, but as time went on, wells were dug back from the springs.

Digging and cribbing wells by hand was a tedious and uncertain process, and in 1806 two brothers, David and Joseph Ruffner, took a revolutionary step. On the banks of the Kanawha River above Charleston, West Virginia, at the Great Buffalo Lick, they set to work to ascertain, by drilling, the source of the salt

water and to obtain, if possible, a much larger quantity of better quality brine for manufacturing salt on a scale commensurate with the growing needs of the country.

The successful boring of the Ruffner well and the resulting spread of the salt industry has never received the attention it deserves nor the recognition it should have as laying the foundation of the future great American industry in petroleum. In nearly all of these salt wells petroleum made its appearance and was a source of considerable annoyance. Nevertheless, the occurrence of petroleum was thus marked, waiting only for the impetus of economic demand to direct man's attention from salt to oil. Of even greater importance to the future oil industry was the development of the fundamental principles of the mechanics and equipment of deep well drilling—the boring tools that were the result of the ingenuity and resourcefulness of the Ruffner brothers.

The Ruffners were confronted, first of all, by 16 or 17 feet of "mire and oozy quicksand" through which they must penetrate in order to reach bed-rock. To do this, they provided what was technically called a "gum"—a straight, hollow sycamore tree, 4 feet in diameter, set upright and held in place by props or braces, with a platform wide enough for two men fixed about the top. A large bucket made of half a whiskey barrel was suspended in the gum by means of a rope attached to the end of a sweep, the fulcrum of which was a forked post set in the ground close by. With one man inside the gum, armed with pick, shovel, and crowbar, two men on the platform on top to empty and return the bucket, and three or four to work the sweep, the crew and outfit were complete.

When at last bed-rock was reached, it was found that salt water was welling up through the rock. Although the quantity was small, the increased strength of the brine encouraged deeper boring. Recalling the methods used by rock blasters, the Ruffners fixed a long iron drill with a 2½-inch chisel bit of steel to the free end of a 20-foot spring-pole, which was mounted on a forked stick, and fastened to the ground at the other end. Stirrups, also attached to the free end of the pole, were used by two or three men in producing the necessary churning motion, their weight pulling the cable down, while the elasticity of the pole served to jerk it back with sufficient force to raise the tools a few inches.

In this way the boring went on slowly and laboriously until, in January, 1808, at a depth of 57 feet, 40 feet of which was through bed-rock, the Ruffners felt that the flow of brine was sufficient to justify their undertaking.

At this point another unprecedented difficulty confronted them—the problem of closing off the flow of weaker brines and fresh water from above. Metal tubing would naturally be their first thought, but there were neither metal tubes nor sheet metal nor metal workers in the region. So they had to invent, contrive, and construct anew. To bore a wooden tube 40 feet long and small enough in external diameter to go in the 2½-inch hole, was impracticable; what they did was to improvise a casing by whittling two long half-tubes of wood of the proper size, and, fitting the edges carefully together, wrapping the whole from end to end with

small twine. This casing, with a bag of wrapping near the lower end to make it water-tight, was cautiously pressed down to its place, and found to answer the purpose perfectly; the undiluted brine flowed up freely through the tube into the gum, from which it was raised by the simple sweep and bucket.

As Dr. J. P. Hale, early West Virginia historian, stated,

> Thus was bored and tubed, rigged and worked, the first rock-bored salt well west of the Alleghenies, if not in the United States. The wonder is not that it required 18 months or more to prepare, bore, and complete this well for use, but rather that it was accomplished at all under the circumstances. Without preliminary study, previous experience or training, without precedents in what they undertook, in a newly settled country, without steam power, machine shops, skilled mechanics, suitable tools or materials, failure rather than success might reasonably have been predicted.

Important improvements were gradually made in the manner of boring, tubing, and pumping wells. The first progress made in tubing after Ruffner's compound wood-and-wrapping-twine tube, was the substitution of tin tubes, soldered together as they were put down the well. The refinement of screw joints had not yet come, but followed shortly after, when first copper and then iron pipes replaced those of tin.

In 1831 Billy Morris, a very ingenious and successful well borer, invented a simple tool which did much to render boring practicable, simple, and cheap. This tool was given the name of "jars" in the oil regions and was adopted into general use wherever deep boring was done.

The efforts of the Ruffner brothers were followed by other and deeper borings, in nearly all of which petroleum accompanied the brine. At that time, however, oil not only had little or no value, but was considered a general nuisance and every effort was made to get rid of it. The petroleum was allowed to flow over the top of the salt cisterns to the Kanawha River, where it spread many miles downstream, thus earning the nickname "Old Greasy" from the Kanawha boatmen.

Natural gas, like oil, was incidental to salt production. The first recorded flow of gas ever struck was in a well drilled in 1815 by one Captain James Wilson, within the present city limits of Charleston.

> The Captain had not gotten as good salt water as he expected; but instead of being discouraged, he declared in language emphatic, that he would have better brine or bore the well into Hell. Shortly after this the auger struck a cavity which gave vent to an immense flow of gas and salt water. The gas caught fire from a grate near at hand, and blazed up with great force and brilliancy, much to the consternation of the well-borers and others. Captain Wilson thought it would be reckless tempting of providence to go any deeper, and ordered the boring stopped.

In a few instances in the early history, gas struck while drilling for salt was utilized for heat and light; but for the most part it was allowed to escape into the air, serving only as an object of wonderment and awe to the passer-by. Dr. Hale writes of the Messrs. Dickinson and Shrewsberry, who, in 1843, boring a few rods below General Washington's "burning spring,"

tapped at about 1,000 feet in depth, nature's great gas reservoir of this region. So great was the pressure of this gas, and the force with which it was vented through this bore-hole, that the auger, consisting of a heavy iron sinker, weighing some 500 pounds, and several hundred feet more of auger poles, weighing in all, perhaps 1,000 pounds, was shot up out of the well like an arrow out of a cross-bow. With it came a column of salt water, which stood probably 150 feet high. The roaring of this gas and water, as they issued, could be heard under favorable conditions for several miles.

While this well was blowing it was the custom of the stage drivers, as they passed down by it, to stop and let their passengers take a look at the novel and wonderful display. On one occasion a professor from Harvard College was one of the stage passengers, and, being a man of investigating and experimenting turn of mind, he went as near the well as he could get for the gas and spray of the falling water, and lighted a match to see if the gas would burn. Instantly the whole atmosphere was ablaze, the Professor's hair and eyebrows singed, and his clothes afire. The well-frame and engine-house also took fire, and were much damaged. The professor, who had jumped into the river to save himself from the fire, crawled out, and back to the stage as best he could, and went on to Charleston, where he took to bed, and sent for a doctor to dress his burns.

Colonel Dickinson, one of the owners of the well, hearing of the burning of his engine-house and well-frame, sent for his man of affairs, Colonel Woodyard, and ordered him to follow the unknown stage passenger to town, get a warrant, have him arrested and punished for wilfully and wantonly burning his property,—"unless you find that the fellow is a natural damned fool, and didn't know any better." Arriving at Charleston, Woodyard went to the room of the burnt Professor at the hotel, finding him in bed, his face and hands blistered, and in a sorry plight generally. He proceeded to state in very plain terms the obiect of his visit, at which the Professor seemed greatly worried and alarmed, not knowing the extent of this additional impending trouble, which his folly had brought upon him. Before he had expressed himself in words, however, Woodyard proceeded to deliver, verbatim, and with great emphasis, the codicil to Dickinson's instructions. The Professor, notwithstanding his physical pain and mental alarm, seemed to take in the ludicrousness of the whole case, and with an effort to smile through his blisters, replied that it seemed a pretty hard alternative; but under the circumstances, he felt it his duty to confess under the last clause, and escape. "Well," said Woodyard, "if this is your decision, my duty is ended, and I bid you good morning."

For many years this natural flow of gas lifted the salt water 1,000 feet from the bottom of the well, forced it a mile or more through pipes, to a salt furnace, raised it into a reservoir, boiled it in the furnace, and lighted the premises at night.

The success of this well induced other salt makers to bore deep wells for gas, and several were successful, using the gas either alone, or in connection with coal for fuel in salt making. Gas was also struck in a few other wells, but did not last long, and was not utilized.

The Ruffners must have viewed with considerable satisfaction the opening of a new era in the salt industry, for their revolutionary methods spread through the salt producing regions of the country with considerable success. The number of salt wells increased rapidly, and certain areas later to be famous as petroleum fields were first known for their salt wells—the valley of the Muskingum from Zanesville to Marietta, Ohio, and the valley of Duck Creek (center of the Washington County petroleum fields). Others did not attain fame as salt centers be-

cause of the hindrance of issuing oil, such as the area around Tarentum, Pennsylvania, the Big Sandy River and its tributaries in West Virginia, Kentucky, and in northern Tennessee. Wells were drilled to depths of 475 feet or more as early as 1814, and the famous "American Well" near Burkesville, Kentucky, was reputed to have struck a "vein of pure oil . . . producing thousands of gallons a day." Thus petroleum was found at greater depths and in larger quantities than in the famous Drake well, long before Colonel Drake was born.

No one event, nor any one person was responsible for ushering in the "Oil Age" of American industry. During the first half of the 19th century the stage was being set—man learned where oil could be found and how to obtain it; all that was lacking was the spark of economic incentive.

A market of sorts in petroleum, mainly for medicinal purposes, had existed for many years. Sometime around 1806 the first shipment of petroleum was made from Oil Creek to Pittsburgh by Nathaniel Cary, who, possessing perhaps a little more enterprise than his neighbors, collected or purchased a cargo of oil and proceeded to Pittsburgh to exchange it for commodities needed by his family. This cargo consisted of two 5-gallon kegs, that were slung one on each side of his horse, and thus transported by land a distance of 70 or 80 miles. Sometimes the market in Pittsburgh became very dull, for a flatboatman would occasionally bring down a barrel or two on his raft of lumber or logs. The introduction of a barrel or more at one time was enough to glut the infant market and spoil Mr. Cary's traffic.

A broader utilization of petroleum and natural gas was constantly being urged by some more far-seeing men, with little success. As early as 1814 DeWitt Clinton, remembering the lamps of Amaino, Italy, suggested that petroleum from a bituminous spring in Allegheny County be tested for illuminating purposes. In 1821 natural gas was used for lighting the houses of Fredonia, New York; and in 1828 petroleum was recommended in the Pittsburgh Gazette as being the best and most economical light available. At a later date a mixture of petroleum and whale oil was successfully tried as a lubricant for the cotton spindles of the Hope Cotton Factory in Tarentum, Pennsylvania.

The second quarter of the last century marked the introduction of new enterprise—the development of the shale oil industry in western Europe and eastern America. The transition from cottage handcraft to factory manufacture called for more and better artificial lighting, and the ever-increasing number of factory machines demanded lubricants.

Up to this time whale oil had fed the lamps and machines of America, but more and more ships were joining the idle whaling fleets in the New England ports. With the diminishing supply and rising price of sperm and whale oil, the necessity for a cheaper substitute was becoming more acute and furnished the motivating power for greater activity in analytical and experimental research on the properties and possible utilization of petroleum and its derivatives.

Oil had been distilled from coals and shales in Great Britain as far back as

1694; but it was not until about 1850 that experimental work, resulting in practicable commercial production of kerosene from coal and oil shales, led to the establishment of 130 plants in Great Britain and 64 in this country. With oil at 50¢ a gallon in 1860 immediately following the drilling of the Drake well, the bankruptcy of these extensive oil works was inevitable.

One of the little known, and yet important figures in the coming drama of the Drake well was one Sam Kier of Tarentum, Pennsylvania. He, himself, probably never was aware of the role he played. In 1847, Sam and his brother Thomas leased a piece of land near Tarentum for the purpose of boring salt wells. They drilled two wells to depths of over 400 feet, and one of these wells produced oil. The Kiers accumulated a large quantity of oil but could find no market for it. Sam, his practical sagacity undaunted by their initial failure, opened an establishment in Pittsburgh where his petroleum was put up in half-pint bottles and sold for 50¢ a bottle as a panacea for the ills of mankind. His advertising campaign included the distribution of circulars printed to represent banknotes, setting forth the wonderful curative powers of his oil, which was obtained from a salt well at a depth of 400 feet.

Meanwhile, advancing prices of rock oil and the growing knowledge of petroleum and its uses as lamp oils, paraffin, and lubricants were developing widespread interest in petroleum in America. One of the most interested was George H. Bissel, a lawyer of New York, to whom $2 a gallon for crude oil was sufficient incentive for abandoning a legal career. Mr. Bissel was then a trustee of the Pennsylvania Crude Oil Company, made up mainly of New Haven capitalists, for the purpose of leasing and exploring for oil on Watson's Flat, Oil Creek, Pennsylvania, where oil seepages occurred.

Four years after its printing, in 1856, one of Sam Kier's banknote circulars came to the attention of Mr. Bissel, and brought to him the idea of drilling for petroleum. After a favorable analysis and report on the quality of the Watson's Flat oils by Prof. Benjamin Silliman, Jr., professor of chemistry and natural sciences at Yale, the original Pennsylvania Crude Oil Company was reorganized, called the Seneca Oil Company, and the wheels set in motion for the drilling of the first well bored for the specific purpose of obtaining oil. E. L. Drake was appointed superintendent of the property of the Seneca Oil Company, and a drill crew was brought from one of the Kanawha, West Virginia, salt-well districts.

Drilling was started about the middle of May, 1859, and in three months the drill had bored little more than 69 feet, 30 feet of which was into bed-rock. On Saturday, August 28, the drill fell 6 inches into a crevice, making the total depth of the well 69½ feet. The next day, Sunday, the head driller, Uncle Billy Smith, on visiting the well found it nearly full of oil.

Excitement ran high in the village and spread like wildfire through the country. Then began the tumultuous days of racing for leases and wild speculation in oil properties; the days of the colorful oil scouts, gaugers, and "soup wagon" drivers; of drilling wells as fast as money and equipment could be obtained, some-

times resorting to the original man-powered spring-pole methods in fevers of impatience.

In some petroliferous regions the presence of a reservoir is indicated by surface manifestations, such as oil and gas seepages, deposits of brea and asphalt, bituminous dikes, tar sands, and mud volcanos. Any such indication, or a trace of oil in a water well or spring was enough to draw some oil-hungry wildcatter. Remembering where oil had polluted the salt wells, men extended their search to West Virginia, southeastern Ohio, and eastern Kentucky. In the same year a show of oil was encountered in a shallow well near Paola, Kansas, and two years later a small well was brought in near Florence, Colorado. In 1867 production was obtained in Wyoming, and by 1875 two small fields in the Los Angeles Basin were producing. Thus in 16 years the petroleum industry had proceeded across country and reached the Pacific.

Besides being the first successful well in Texas, the well drilled by Lynis T. Barrett at a seepage near his home in Nacogdoches County, Texas, in 1865, was further famed for being the first employing the rotary principle.

Refineries, of necessity, followed immediately and sprang up both near the wells and in every city within reach of the field. All, however, were primitive and their products far from uniform—the kerosene sometimes carrying gas oil and sometimes gasoline. It has been said that when a man lighted a lamp he never knew which it would do, smoke or explode.

To one man more than any other, whatever methods he may have used, must go the credit for bringing some semblance of order into this boisterous new industry. It was John D. Rockefeller, who saw that this vast gambling game could be controlled through refining and transportation, and with this control came a more stable price structure and more uniform products.

1860—THE BEGINNING OF PETROLEUM GEOLOGY

FIRST THEORIES PERTAINING TO OIL AND GAS OCCURRENCE

Within a few years after the drilling of the Drake well, several geologists were attempting to find a method for determining the best locations for prospecting and some means of predicting the results of drilling. It was noted that oil occurred chiefly on arches, that it should not be sought for in synclines nor in areas of undisturbed strata, that it probably originated in beds of bituminous shales rather than in coal beds, and that accumulation could take place under favorable structural conditions only where an impervious cover was present.

H. D. Rogers, of Pennsylvania and Virginia fame, who was unquestionably the leading structural geologist of his time, before the Philosophical Society of Glasgow in 1860, announced the indicated correlation between dynamic and temperature metamorphism, coal composition, and the occurrence of oil and gas. He continued to publish his views on the subject, and in 1863, in an article on coal and petroleum, set forth clearly his theories regarding the nature, localization, and marine character of "source beds"; the processes and conditions responsible

for the concentration of oil into pools; and the vertical and horizontal variations in the metamorphic influences which have affected the oil producing and coal bearing formations since deposition. In fact, the article contained the fundamental principles of the carbon ratio theory (14, 41).

In 1860 Alexander Winchell ventured the theory of origin by distillation from black shale; and the "anticlinal theory" of oil accumulation, foreshadowed by Sir William Logan in his studies of the Gaspé region in 1844, H. D. Rogers in 1860, and others, was fully formulated by T. Sterry Hunt in 1861 and by E. B. Andrews at a closely following date (15). It seemed, however, to have won little or no favor with the oil industry. Drilling for new fields continued to be based upon chance wildcatting, proximity, topography, "oil lines," "creekology," and other unscientific means, in general totally without regard for local geologic structure or a geologist's opinion.

It was a popular saying among practical oil men that "geology never filled an oil tank," and one prominent producer remarked that if he wanted to make sure of a dry hole he would employ a geologist to select the location (45).

"ANTICLINAL THEORY" OF I. C. WHITE

This impasse between geology as a science and its practical application held until broken by the efforts of two men, I. C. White of West Virginia, and Edward Orton of Ohio. The battle began in 1885 with the rediscovery or revision of the anticlinal theory by I. C. White and his demonstration by concrete example of the positive value of geology in locating drilling sites and of the negative value in condemning immense areas for both oil and gas where a search for either would have certainly been in vain at the possible drilling depths of that time.

Dr. White's theory of oil and gas accumulation is in agreement with and includes the essentials of oil and gas accumulations as they are known to-day. It is perhaps unfortunate that the term "anticlinal theory" was applied to his observations, because they were far more comprehensive. He recognized the part played not only by structure but by sedimentation, fracture, convergence, porosity, and permeability.

In 1889 the first well to be located from purely scientific deductions in accordance with his theories concerning oil and gas accumulation was drilled near the town of Mannington, West Virginia, 25 miles distant from the nearest producing field. This location proved to be the discovery well of the rich Mannington oil pool. Dr. White regarded the first Mannington well as the crucial test of his theories, since if the well should have proved a failure, oil geology would have received a fatal blow in the sight of practical oil men, whereas if successful their confidence in geology would be greatly increased and strengthened (45).

However, the success of this field and others following it did not provide an immediate acceptance of geology by the field of industry. White himself stated that he struggled for 8 years for recognition of his ideas, not only among oil men but by fellow members of the geologic fraternity.

Nevertheless, I. C. White, together with Edward Orton, came to be regarded as the foremost authorities on petroleum in the geologic world of 50 years ago. White's applications of his theories and Orton's able championship, critical observations, and consistent conclusions marked a new period in the study of oil and gas, and caused their work to be considered unparalleled in American geology (13).

RÉSUMÉ OF GEOLOGIC THOUGHT IN 1888

The first treatise presenting a résumé of the state of knowledge of petroleum geology was published by Orton in 1888 (13). It included a summarization of contemporary thought on origin, reservoirs, permeability, structure, and pressure:

Origin.—

1. Petroleum is derived from organic matter.
2. It is much more largely derived from vegetable than from animal substances.
3. Petroleum of the Pennsylvania type is derived from the organic matter of bituminous shales, and is of vegetable origin.
4. Petroleum of the Canada type is derived from limestones, and is probably of animal origin.
5. Petroleum has been produced at normal rock temperatures (in Ohio fields) and is not a product of destructive distillation of bituminous shales.
6. The stock of petroleum in the rocks is already practically complete.

Reservoirs.—Reservoirs were noted to be: first, sandstones buried in shales, the overlying shale the cover or roof of the reservoir and the underlying shale the source from which the bituminous products were derived; and second, limestones in which the accumulated stocks of both oil and gas were always found in the uppermost beds of the stratum, carrying at a lower level a brine of unusual character. "The facts as to the occurrence of oil and gas in this stratum seem reconcilable with the theory that they have risen through the limestone rock until they find themselves arrested in their ascent by the overlying shales, and their accumulation therefore takes place at this point." The presence of an approximately impervious roof over the oil reservoir was the primary requisite of oil accumulation.

Permeability.—The previous conception of "crevices" in rocks to account for their productivity was abandoned in favor of the conclusion that the yield of oil wells was fully accounted for by the presence of the oil in the pores of the reservoir.

It was early established in Pennsylvania that different portions of the oil sands communicated with some degree of freedom, for adjacent wells were found to affect each other's yields. In contrast, it was found that in other areas "there was no necessary and absolute connection between different portions of an oil sand"—the stratum might be divided into lenticular masses which might be nearly or entirely disconnected. It was observed that in the limestone reservoirs the same freedom of communication did not exist as in the sandstones; in the case of sandstones, however, it was apparently not realized that lack of porosity

was one of the reasons for lack of communication but rather attributed to changes in thickness and lensing.

Structure.—Although the setting forth of the principles of oil and gas accumulation by I. C. White was regarded by Orton as an epochal work marking a new period in the study of the geology of oil and gas, the "anticlinal theory" was by no means accepted by all geologists. Particularly bitter was the opposition offered by Lesley, Ashburner, Chance, and Carll of the Second Pennsylvania Survey.

With the extension of oil and gas production to areas other than western Pennsylvania, it was soon found by the geologists working in them that modifications of White's theory were required to explain all the structural problems that arose. With an undulating axis the commercial accumulations were found to be confined to the domes, and an "arrested anticlinal" or terrace was another type of structural deformation controlling accumulation.

Pressure.—Orton seems to have been the first geologist to understand the function of artesian pressure in relation to the pressure of oil and gas in the same stratum. He said:

> In the porous rock that contains them there is always, outside of the productive fields, a body of water, and in almost every instance, salt-water. This water occupies the rock as it rises today in its nearest outcrops. Communicating there with surface water or rainfall, a head of pressure is given to the gas and oil that are held in the traps formed by the anticlinals or terraces into which the stratum has been thrown. The amount of pressure would thus depend on the height to which the water column is raised, in case continuous porosity of the stratum can be assumed.

Later Orton published a paper on the origin of rock pressure in the Trenton limestone which laid the foundation for all later studies in dynamic geology as related to oil and gas.

The pioneer work of the geologists of that time placed the science of petroleum geology on a sound foundation.

TECHNICAL ADVANCEMENTS

Advances in technical methods accompanied progress of geologic thought and proved to be of considerable importance in the later development of oil fields. Instrumental determinations of the altitudes of "key" rocks led to the development of structure contours. J. P. Lesley is said to have been the first to introduce this method in the United States in 1858 in the mapping of coal. However, the first known published structure contour map of an oil field was of the Punjab oil lands in 1870 by B. S. Lyman, nephew and student of Lesley (15). Structural contouring proved to be of unparalleled value in the ever-expanding search for structural traps and in the delineation of possible productive strata.

Although national economy was not yet demanding steps towards conservation, I. C. White had noted the possibility of storing gas in natural reservoirs and recommended to gas companies that high pressure wells be connected with par-

tially exhausted wells, thus preventing too high pressure in the pipe lines and at the same time preserving for useful work the surplus gas which would otherwise be wasted into the air (46).

1900—THE GASOLINE AGE

INCREASE IN ECONOMIC DEMAND FOR PETROLEUM

Following the development of the high-speed internal combustion engine by Daimler and the automobile later devised by him, gasoline was brought from its lowly estate as a waste product to a position of importance far exceeding that of kerosene (44). In the early years of distillation of Pennsylvania crudes, one of the refiner's chief problems was the disposal of the large quantities of gasoline produced in addition to kerosene. But the development of automobiles, from curiosities in the nineties to household necessities to-day, brought us the gasoline age from the early 1900's to the present (10).

The rapidly increasing demand and market for petroleum and its derivatives motivated both horizontal and vertical expansion of search. The discovery of new types of occurrence, such as the salt-domes of the Gulf region, and the fault zones of Texas, opened new vistas for geologic research. The vertical expansion of deeper drilling, involving an outlay of several hundred thousand dollars as compared to the relatively small cost of the first wells, was bringing about the slow realization of the value of scientific consultation in the field before drilling was even attempted. The oil industry was gradually coming to rely less and less upon the wildcatter to bring in new fields and was recognizing the effectiveness of various branches of science in throwing light upon the definite finding of oil.

The early years of the twentieth century, before World War I, were marked principally by the development of a series of spectacular oil fields, increasing recognition of the possible advantages of utilizing geologic methods in the discovery of oil fields, and by advances in geologic knowledge.

DEVELOPMENT OF FIELDS

The first successful drilling of a salt dome at Spindletop, Texas, in 1901, by Captain A. F. Lucas, was one of the most widely publicized events of petroleum history, and opened the way to the development of the entire salt-dome belt of the Gulf coastal plain west of the Mississippi River, and later in Louisiana (2).

Besides being the first field on a salt dome, Spindletop had the distinction of being the most prolific single field that had yet been opened and the first field in the Gulf Coast district. Within a year Texas had passed Pennsylvania and was crowding Ohio for first place in production. It was not Texas, however, but California, with its famous San Joaquin Valley fields, which passed Ohio's production in 1903. While attention was concentrated on the spectacular fields of California, production was steadily working southward in Oklahoma, until the Glenn pool there raised Oklahoma to the leading position in 1907 (2).

INCREASING USE OF PETROLEUM GEOLOGY

After the general structural conditions in these big fields were thought to be understood, a number of geological consulting firms were organized. By 1908 a few oil companies were cautiously following geologic advice. David White says, "So skeptical were some of the companies that reports by their geologists were filed until several years later when confidence had grown." As the resulting economic advantages to these companies became quickly apparent and as the reports of the United States Geological Survey and State Surveys' mapping the structure of numerous areas became known to them, companies quickly adopted geologic guidance and methods of investigation. Large staffs were hastily recruited—to the depletion of first the Geologic Surveys and Bureau of Mines, and finally of the university departments of geology.

ADVANCES IN GEOLOGIC KNOWLEDGE

In January, 1915, David White, chief geologist of the United States Geological Survey and an outstanding paleobotanist, in his presidential address before the Washington Academy of Science, announced his Carbon Ratio theory. The theory was primarily a formula for determining the presence or absence of oil and gas by measuring the amount of metamorphism the rocks had undergone, as indicated by the percentage of "fixed carbon" shown by proximate analyses of coals, calculated to the ash-free basis.

The demand for oil following World War I led to intensified exploration, and an accurate criterion for differentiation between areas of maximum promise and barren or unpromising territory was badly needed. Numerous articles were written and carbon-ratio maps published discussing and describing the carbon-ratio situation in relation to existing fields. During the 1920's especially, rather heated debates developed on the pros and cons of the scientific validity and the practical utility of the theory as applied to oil exploration. As a matter of fact it is not yet completely settled, although it would probably be agreed by all that there would be a degree of metamorphism beyond which volatile hydrocarbons could not retain their character (1, 41).

1917—THE PETROLEUM GEOLOGIST

ORGANIZATION OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

A most important date in the history of petroleum geology was 1917, when The American Association of Petroleum Geologists was organized. This marked the period when petroleum geology "came of age." The willingness of geologists to exchange ideas and techniques indicated a great advancement in the development of that branch of the science. Since 1917 the A.A.P.G. has exercised the dominant influence in the field of petroleum geology, and through its publications has recorded the facts and theories of its members—presenting a cross section of petroleum geology thinking.

Although in Oklahoma several of the larger companies had commenced em-

ploying geologists as early as 1913, relatively few geologists were employed in the search for new oil fields. The increase in commercial employment was slow during 1913–1915, but informal gatherings and dinners among the geologists themselves grew in number and size from 1914 on, finally leading to the organization of the Southwestern Association of Petroleum Geologists in 1917, renamed The American Association of Petroleum Geologists a year later. The first published membership list contained 94 names, and from that modest beginning has grown the largest geological society in the world with a membership of 4,676, scattered through 43 of the states and as many foreign countries (29).

RESULTS OF WORLD WAR I

The demands imposed by war on oil production and the experiences developed during the course of the war forcefully demonstrated the importance of maintaining adequate petroleum reserves. The shortage of oil during the war and the growth of appreciation by the oil industry of the importance of scientific methods of prospecting, coupled with the ability of the oil industry to spend large sums of money in search of new fields were the basic features in the following pyramidal rise of petroleum geology (3).

Employment of geologists by industry.—One of the first specialized branches of geology to be incorporated in industry was the field of paleontology, particularly micropaleontology, and, several years later, the allied field of micromineralogy (5, 9, 17, 36). Chapman had introduced the study of foraminifera in 1900 with his examination of a well cutting from a bore-hole in Santa Clara County, California. Further research demonstrated the effectiveness of paleontology in the identification and correlation of strata, and led to the gradual application of paleontological research in industry. In 1918 the Rio Bravo Oil Company, and soon afterward the Humble Oil Company, established in Texas the first laboratories to utilize paleontology in the search for oil; and within a few years most of the large oil companies had paleontological laboratories.

In the days when the petroleum geologist was mainly concerned with source beds, reservoir rocks, and particularly structural traps, the importance of the identification and correlation of key beds brought the paleontologist into his own. With the later concentration on stratigraphic traps, it was found that the correlation difficulties presented by the complex and rapidly changing lithologic character of the beds were best solved by a study of the contained faunas supplemented by detailed petrological investigations and by electrical logging.

Development of geophysics.—An allied science which developed rapidly as a result of the demands of war and the subsequent release of funds for research was the science of geophysics. In those days a quarter or more of the total production of a well was realized during the first year, and a half or more of the entire potential output was produced within three years. The oil industry was therefore in a position to spend a great deal in experimentation with new methods of discovering oil deposits (3).

The first important event in geophysical search for oil came in March, 1924, with the discovery of the Nash salt dome of Texas. The development of five domes by refraction and torsion-balance crews within less than a year greatly impressed oil executives with the importance of these methods, so that the next 5 years saw what Barton has called an "explosive" expansion of geophysical research. Further development in precision of instrumentation and interpretation was as great as the expansion and use of this new science. The following years of accumulated experience indicated the extent and limits of effective geophysical application. The high cost precluded wide general surveys; it was still the geologist who delineated the wider areas of possible production, leaving the smaller units for more detailed geophysical study.

Conservation and estimated reserves.—The post-war efforts of European nations to procure oil territory in different lands in as large areas as possible for the protection of their future, brought somewhat abruptly to the delinquent attention of America the question as to the status of this country when the exhaustion of our wastefully exploited oil resources should cause acute shortage (44).

We have always been prodigal with our resources, ever since the early days when oil was thought to flow underground in a never-ceasing stream, and gas was inexhaustible because the internal heat of the earth was constantly generating gas from coal. However, the petroleum geologist has always stood for conservation, for the maximum efficiency of utilization and minimum of waste. As early as 1886, C. A. Ashburner proffered suggestions for the conservation of natural resources in a paper, "The Production and Exhaustion of the Oil Regions of Pennsylvania and New York." The Government policy of conservation was actively carried into the realm of petroleum and gas by I. C. White, David T. Day, and others. White called attention to the waste of our fuel resources before the conference of Governors at the White House in 1906, and Day prepared an inventory of our national oil reserves at the same time. He estimated between 10 and $24\frac{1}{2}$ billion barrels, with depletion in 1935 or 1943 (27).

Within a few years after the discovery of the Drake well, periodic alarms were raised that we could not satisfy for long the national need for petroleum. There has hardly been a 5-year period since that time in which someone has not made dire predictions that our oil resources were nearing exhaustion. Yet, almost invariably, immediately upon the heels of such alarms, new discoveries have been made and new methods developed for the extraction of crude oil from the earth (27).

In 1922 the American Petroleum Institute first made a distinction between proved and unproved reserves. Since that time it has been customary for prognosticators to estimate "proved reserves" as the oil underground in areas which have been proved by drilling and which have oil economically recoverable by producing systems now in operation. Nevertheless, the possibility of exhaustion continued to be brought forward during the late 20's and into the 30's, when the discovery of the amazingly productive East Texas pool silenced all pessimists, for a time at least (27).

Technical developments.—One of the most important technical outgrowths of the war was the development of the aerial photograph, which came to be widely used by the petroleum geologist as a discovery tool. Its chief value lay in the economy of being able to cover large areas in a short time, the ease of surveying, and the rapid discovery of indications of favorable structural areas (6).

1930—MODERN PETROLEUM GEOLOGY

TRANSITION INTO MODERN THINKING

In many respects 1930 marks the beginning of our present concepts of petroleum geology. The realization that oil and gas might be trapped by strictly sedimentary or stratigraphic conditions turned general recognition to a new type of reservoir known as the stratigraphic trap, and concentrated the efforts of a group of workers to a line of attack that I like to think of as "putting the reservoir under the microscope."

The transition into what may be called modern geologic thinking is outlined by a series of publications by The American Association of Petroleum Geologists:

The Association's 2-volume symposium, *Structure of Typical American Oil Fields*, edited by Sidney Powers, appeared in December, 1929. Although the contributions dealt with every phase of oil geology, the fields described were primarily selected with reference to structural conditions.

This was soon followed (1934) by another volume, a symposium—*Problems of Petroleum Geology*, edited by W. E. Wrather and F. H. Lahee. This volume, as indicated in the preface, was "designed to review, modify, and, if possible, clarify our ideas with regard to the fundamental concepts of oil geology . . . essentially it is a progress report, bringing down to date our views on the theories of origin, migration, and accumulation of oil, modified by such new facts as have become available."

This volume had a most wholesome effect in that it focused attention for further study on points of weakness. Traps other than anticlinal or domal were recognized for the first time and included by W. B. Wilson in his well known classification. With the recognition of the importance of stratigraphic traps, the dominant trend in the thinking of the petroleum geologist during this period (1930 to present) turned to the detailed fields of sedimentation and stratigraphy, porosities and permeabilities.

Levorsen's research committee's survey of the Association's membership in 1939 showed this to be true, and there followed the Association's timely volume, a symposium—*Stratigraphic Type Oil and Gas Fields*, in 1941.

The research committees of the Association have always been active in keeping before the membership a summary of existing knowledge and outlining problems on which further investigation need be made. Our present committee under the capable chairmanship of S. W. Lowman, was most active during 1945 and set forth in its *Progress Report, Research Committee, January 15, 1946*, what the

leaders in the various fields of research affecting oil discovery were thinking and working upon.

PRESENT TRENDS IN GEOLOGIC THINKING

The quantity of data that has accumulated in the last half-century on the mechanics of petroleum genesis and accumulation makes it difficult to present a brief recapitulation of present geologic thought, as compared to Orton's summary in 1888. The basic principles set forth 50 years ago regarding the history of petroleum occurrence and accumulation was work so well done that little has been discarded, and while many uncertainties and generalities have been cleared away, there yet remains much to be known.

Any consideration of the problem of origin has been based upon the assumption that environmental conditions of the past are analogous, in kind if not degree, to those of the present.

> Opinions differ regarding the usefulness of studies of modern environments in solving the problems of ancient sediments. It may be true that many ancient sediments were formed in environments which have no exact counterparts today, but it is very likely true that the same physical and chemical laws in operation today were in operation during the earth's past history. Hence, although the particular combination of environmental factors may not be the same, the individual processes unquestionably were (18).

Origin.—At the present time the organic theory of petroleum origin is generally accepted, the prevailing opinion of geologists being that the organic mother substance of petroleum was deposited in near-shore marine sediments under essentially anaerobic conditions. However, Gardner has recently restated that all petroleum and natural gas deposits are not necessarily of organic origin (43).

Opinions have differed regarding the types of organic material required to produce oil and gas, Trask holding that the more resistant complexes and not the higher plants are the leading sources (42); and Snider, on the other hand, stating that almost any kind of organic material may produce petroleum and gas (37, 38). It is generally supposed that the distinguishing characteristics of the petroleum found in deposits of different ages are related to the nature of the particular organic material present in the area where the petroleum was formed at the time of its origin.

The problem of conversion of organic material to petroleum was first seriously considered about 1918. The manner in which the change occurred has been left largely to chemists and biologists (13). A few geologists, however, have been actively interested in this phase of petroleum genesis. The two processes considered have been: (1) metamorphism, and (2) bacterial action. David White stated that "dynamic and chemical metamorphism in the course of geologic time, which itself seems to be an important factor, caused dehydration and progressive elimination of the volatile material from the organic sediments, concomitant with gradual lithification." The importance of bacterial action in removing oxygen and nitrogen from organic matter, forming compounds more closely related to petroleum than the original organic material and thus facilitating the generation of

petroleum by purely chemical action, was discussed by Hamar and Trask. The recent work of ZoBell has further amplified the importance of bacterial action in petroleum formation (43), and is regarded as one of the most important lines of research to-day.

The study of the relation of radioactivity to petroleum genesis, as set forth by Sheppard, Mead, and Russell, is perhaps the most recent line of specialized research to be followed in regard to oil and gas origin (43).

Migration.—The many factors and considerations involved in the migration and accumulation of hydrocarbons constitute one of the major problems of petroleum geology. The functions of micro-organisms, the factors of heat, pressure and chemical action, source beds, circulation of subsurface waters, compaction of sediments, the oil-water contact, time of accumulation, *et cetera*, have been topics of research of many petroleum geologists (13).

The compaction of sediments with increasing load and the resulting movement of interstitial water is thought to be the principal cause of migration of oil from source beds (Athy, Schilthuis), the outward movement being in the direction of the more permeable strata which are competent to act as carriers (Illing). Capillarity also has been thought competent to cause the movement of petroleum from source bed to reservoir (McCoy); and artesian circulation and diastrophic movements are known to be contributing forces.

Once having entered the reservoir bed, the particles of petroleum which had passed through the capillary pores of the source rock would tend to coalesce into larger globules in the wider interstitial spaces of the carrier bed. These globules would be further screened or filtered out if the water in the carrier bed were forced upward by compression (Illing, Versluys).

The relation of source bed to reservoir has long been the subject of vigorous debate. Clark, McCoy, and Keyte presented the *in situ* theory of juxtaposition of source and reservoir, believing that the amount of migration has been negligible; whereas lateral migration in varying degrees has been sponsored by Rich, who believes that oil may travel great distances in moving from its source to its site of accumulation, and by Adams, who limits the source of oil supply of each producing area to the immediately adjoining territory.

Heroy states that in some manner the petroleum must have been collected from the wide areas throughout which it entered the porous beds and concentrated in the relatively much smaller areas which it is now found to occupy. The movement by which this has been accomplished is essentially lateral movement, one which continues until the petroleum reaches a stratigraphic or structural trap. A combination of the principles of flotation and hydraulic movement (Griswold, Munn, Cheney) seems best to explain the movement of oil and gas to areas of accumulation. More recently it has been stated by ZoBell that bacteria may have played an important part in the migration and accumulation of petroleum in that they may release oil from sedimentary materials and generate carbon dioxide which will decrease the viscosity of the oil and develop internal gas pressure which will tend to drive oil through the strata.

Reservoir traps.—Until the early 30's the petroleum geologist's chief problem in the finding of oil and gas deposits was the location of favorable "structures." As K. C. Heald said,

> In those early days we were busy racing each other; each man was trying to find the next anticline or the next oil field, and every man had a job on which he had to deliver. The general attitude was—you show me an anticline big enough, and I will bore a hole on it and we will let nature take its course and have a reasonable number of oil fields. That was our job (50).

From the wealth of data which had become available with the development of each new field, the original conception of oil and gas accumulation on simple anticlinal folds was expanded and revised to include the more complex structural classifications and their many subdivisions.

Tilting, folding, faulting, and intrusions, resulting from movement which occurred in sedimentary deposits after their deposition, were included in the structural or deformational type of oil and gas accumulation. Any one of these, or any combination thereof is capable of producing an effective trap.

Structural closure by folding was regarded as the most important factor in trap formation. Long Beach is perhaps the most important dome; and Salt Creek, Wyoming, also a domal structure, the most productive field of the Rocky Mountain area. Of similar structure are the Hobbs field of New Mexico, the Yates and Big Lake fields of West Texas, and the Santa Fe Springs, Elk Hills, Kettleman Hills, and others of California (13).

Faulting was not recognized as an important factor in structural accumulations until about 1920, with the discovery of the Mexia field in East Texas. Outside of this district such fields are unusual, although the Whittier and Round Mountain of California are comparable. Overthrust faulting produced such fields as the Turner Valley of Alberta and McKittrick of California (13).

The previously mentioned discovery of Spindletop in 1901 led to the campaign of exploration for the salt-dome type of deformational penetration, and the subsequent development of the famous Gulf Coast pools (13).

The relationship of stratigraphy and sedimentation to production was not unknown, but was considered as subordinate. In 1930, the East Texas pool, the largest field to that day, was discovered. Its development indicated that the important factor there was not closure resulting from dip reversals, but stratigraphy, or change from a porous rock to a non-porous one (13).

The discovery of other fields of the newly recognized stratigraphic trap type resulted in their classification into two main types: (1) Depositional, and (2) Diagenetic (13).

In depositional traps conditions were established when sediments were deposited—reservoir beds wedging out laterally between less permeable strata or changing lithologically; or porous beds (pointing updip) truncated and bevelled by each overlap. The Burbank and Glenn fields of Oklahoma, and the East Coalinga of California represent margins of sands of large regional extent; the shoestrings of Kansas and Pennsylvania being of similar type although of much

smaller areal extent. The East Texas and Oklahoma City fields are examples of porous beds truncated and bevelled.

Diagenetic traps are characterized by changes in petrology of the reservoir rocks subsequent to their deposition. The porosity and permeability of sandstones may be controlled by secondary cementation, as in the Venango sands of Pennsylvania and the Clinton of Ohio; and limestones by solution and recrystallization. Dolomitization has accounted for the porosity of the upper zone of the Trenton in the Lima-Indiana field and, similarly, the Dundee of Michigan and the Arbuckle limestone of the Oklahoma City field.

The difficulty of determining which factor is dominant, structural or stratigraphic, was well stated by Levorsen:

> If we attempt to classify oil fields as being either structural or stratigraphic in type we find on one extreme such a field as Salt Creek, Wyoming, in which the trap may be said to be entirely structural—the local structure anomaly marking the edge of the pool on all sides. On the other hand, if we consider a shoestring-sand pool, such as is common in eastern Kansas, we find that the area of the accumulation is altogether a function of the sand distribution and that local structure plays little or no part in the localization of the pool of oil. Between these two extremes, which might be taken, respectively, as 100 per cent structural and 100 per cent stratigraphic, we find every variation and gradation. As we approach the middle ground between these two types it becomes increasingly difficult to decide whether the dominant trap-making factor is local structure or stratigraphic variation (20).

The first emphasis on structure and the later concentration on stratigraphy precluded for a time a completely satisfactory classification of oil and gas reservoirs. The most recent classification of traps, as developed independently by Wilhelm (48) and by Brod (4) in 1945, recognize that most local traps are caused by combination of structural-stratigraphic or structural-lithologic factors.

SPECIALIZATION

Recent trends subdividing geologic research into more highly specialized fields has been the result of the recognition of the importance of variable porosities, of unconformities, and of the environmental conditions of deposition.

Sedimentation has become a subject of intense importance to the petroleum geologist. However, a workable understanding of the subject as it can be applied to petroleum geology is still in the process of development; so far, research has been principally confined to quantitative or statistical studies, developed for the main part in the geology departments of universities. Its potential importance as a discovery tool has not yet been fully developed. Levorsen states that,

> Sedimentation, with all of its related studies, promises to be of increasing importance and one of the key discovery tools of the future . . . we may well see the day when it rivals structural geology as a way of finding oil.—A real understanding of sediments would probably do more than any other single factor to improve the geological interpretations which are put on geophysical data and in like manner it would improve the speculative geology which is necessary to all subsurface studies (22).

The sedimentary assemblage, considered as a whole, has been developed for only a few sedimentary deposits, as for example the Third Bradford sand described by Krynine (26). More commonly, specialized divisions of sedimentation, such as insoluble-residue studies, heavy mineral concentrations, size and shape analyses, porosity and permeability determinations, have been isolated for specialized research.

The accumulated data already on file in the various Federal and State Surveys and offices of oil companies will form a source of material for future studies. Our own West Virginia Survey has published four large volumes on well records, including approximately 3,000 detailed deep well logs, and sand samples from some 800 deep wells are filed, representing the largest and best collection in the Appalachian area. These samples will provide opportunity for further studies in correlation and in the reconstruction of environments of deposition.

A relatively new specialized field of predicting the presence of oil is the geochemical method of soil analysis, still more or less in the experimental stage. Briefly, it is based on analysis of soil for minute traces of hydrocarbons emanating from petroleum accumulations below. Proponents of this method claim that concentrations of hydrocarbons in soil will be found directly or nearly over the accumulations from which they come. The "halo" theory holds that upward emanations will eventually form an impervious cap directly over the crest, thus concentrating these hydrocarbons traces into a ring outlining the center of the underlying deposit. Current methods of geochemical analysis now favor sampling to 100-foot depths; it being claimed that analysis of shallow samples may lead to false conclusions (42).

Another form of geochemical analysis has been developed at the West Virginia Survey. A detailed survey was made on the composition of natural gas according to geological horizon and geographical distribution within a geologic province. Our results indicate that the composition of the gas offers criteria for prospecting for oil, and indicates relative areal positions of gas and oil in a given reservoir. An Iso-Thv map as an indication of the composition of natural gas in the Appalachian province shows it to coincide more nearly with the sedimentation or depositional environment than with the structure of the region as influenced or controlled by dynamic metamorphism (32, 33).

ENGINEERING TECHNIQUES

The development of engineering techniques in the search for petroleum is so closely allied with geologic knowledge that it is impossible to consider one without the other. Expanding knowledge of genesis, occurrence, and environment must be equalled by engineering procedures for recovery. Wells that reach depths of three miles, encountering pressures of 8,225 psi and temperatures of 200°F. require special engineering skills.

Directional drilling is an accomplishment of the early thirties. When methods of surveying wells were devised, drillers and geologists alike were astounded to

learn that a vertical hole was not the rule. This discovery naturally led to the idea of drilling deviant holes intentionally. After a period of abuse by some drillers with eyes on adjoining leases, it was obvious that under some special conditions directional drilling would prove very valuable in saving expense and in securing more oil production by greater oil sand penetration. Directed drilling made it possible for more convenient drilling sites to be selected to avoid the expense of drilling on inaccessible surface locations such as submerged or precipitous ones, or to avoid considerable hole depth (23).

A few years ago it would have been considered impractical to tap an oil deposit 4,000 feet off-shore by directing a curved borehole along a predetermined course from a drilling site on shore or to erect an island two miles from shore from which a number of wells are drilled directionally to exploit several hundred acres of submerged lands surrounding the island. Yet today in certain Pacific coast and Gulf coast oil fields these are accomplished facts and the techniques are so well established that they are being duplicated in other fields throughout the world (24).

The necessity for technical means of prospecting submerged lands has resulted in recent years in improvements in geophysical methods, notably the construction of gravimeter and magnetometer for under-water operation. It is predicted that aircraft and submarine, as well as surface vessels will be used in conjunction with adapted forms of seismic, gravity, and magnetic prospecting equipment.

Heiland has expressed doubt of the possibility of any radically new prospecting devices resulting from World War II developments in detecting equipment, though geophysics will profit by many war inventions such as the airborne magnetometer, "shoran," and similar forms of radar, the radio altimeter, and radioactivity.

The most outstanding recent developments in production engineering are in reservoir control. The type of reservoir control applicable to any one producing unit varies with conditions in the individual reservoir and includes either pressure maintenance or controlled pressure decline.

SUMMARY AND CONCLUSION

Following a brief review of the historical development of oil and gas in the United States up to the drilling of the Drake well, an attempt has been made to note the more important opinions that have been expressed concerning the geology of oil and natural gas. These have included origin, migration, accumulation, reservoir traps, and their means of recognition. So much has been written upon these subjects that it would be impossible to acknowledge even all of the more important contributions.

In 1888, the fundamentals of petroleum geology as we know them to-day were known by White and Orton especially, and several others. Despite the great progress in specialized geologic knowledge and techniques in discovery methods, there is yet much to be learned. We do not yet know how oil is formed. An exact

knowledge of origin would aid in prospecting; fundamental research now in progress seems closer to giving us some of the answers.

As in all sciences, original ideas in the field of petroleum geology are scarce. Perhaps the greatest single advancement in petroleum geology since the "anticlinal theory" was the recognition that reservoir traps could exist without dip reversals due to deformation, and could result from a change in lithology, giving a stratigraphic type trap reservoir. This type of reservoir greatly complicated the geologist's problem and called for the development of new techniques in his search for location and identification. It required specializations which would give new and sufficient data concerning all phases of sedimentation to permit a reconstruction of depositional environment and deformational history—historical geology under the microscope. The better we know our historical geology the better petroleum geologists we should be.

With greater specialization comes the danger of lost integration, each specialist engrossed with the importance of his own field. Here our Association has performed great service in the past and must continue to serve as the coordinator of the thoughts and efforts of the members of our profession in the future.

As A Rodger Denison stated in his presidential address before the Association at Dallas, "There is an unknown but finite number of petroleum deposits—each one discovered leaves one less to be found. If there are ten thousand needles in a haystack the last thousand will require infinitely more search than the first thousand." This will be equally true of the location of the last thousand oil wells.

The search for additional fields will be limited principally to: (1) extensions to existing fields, (2) deeper horizons, and (3) unexplored areas, including portions of inland United States and Alaska, and especially the continental shelf. Trends in each of these directions are already underway, and the discovery of these new areas of production will require the application of existing geologic knowledge and techniques plus new geologic knowledge and new techniques, and especially their increased coordination.

As Levorsen said in his challenging paper, "Discovery Thinking,"

> Much oil has been discovered by mere random drilling, and much will most assuredly be discovered through such means in the future, but the only rational way to make available to society the oil and gas which now lies underground, as the undiscovered reserve, is through the application of scientific methods and reasoning.

The value of research is appreciated more now than ever before. This was emphasized by the accomplishments during World War II. Our Association's research committee has set the pace in formulating extensive and far reaching plans for the stimulation of fundamental research in petroleum geology. Several major oil companies are constructing or about to construct centers for research in exploration and production.

While we will continue to have our periodic scares about our diminishing petroleum supplies, I have no fear of the industry's ability to continue to meet

the requirements for petroleum products. Long before complete exhaustion of natural petroleum takes place, substitutes for petroleum products will be made efficiently by the conversion of natural gas, by the hydrogenation of coal, and by distillation of oil shales. This transition will take place so gradually that there will be no realization of the exact point at which the change occurred.

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MARINE SEDIMENTARY CYCLES OF TERTIARY IN MISSISSIPPI EMBAYMENT AND CENTRAL GULF COAST AREA[1]

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ABSTRACT

The principles of marine cyclic deposition are discussed briefly and a classification of marine sedimentary cycles is presented. The principles are applied to the Tertiary section of the Mississippi embayment. Five major marine cycles are differentiated, each representing a major transgression of the sea into this embayment.

Facies and thickness distribution of the older Tertiary cycles indicate the presence of a positive area (submarine plateau) in southeast Mississippi, which is bounded on the north and northwest by negative areas (synclines). Isopach studies also show a progressive expansion of this positive area north and northwest during Eocene time, with a corresponding north and northwestward shifting of the bordering synclinal areas. The theory is advanced that the southeast Mississippi plateau constitutes a part of the northern front of the Gulf of Mexico neutral plate, and that its progressive northward expansion is caused by a gradual rise and possible northwestward drift of this plate, in connection with the Tertiary orogenic movements in the Greater Antilles. Epeirogenic movements in the Mississippi embayment and its borderlands are considered to be responsible for the different marine transgressions during the Tertiary. These movements reached a climax at the end of Jackson and during early Oligocene time, after which the sea retreated from the Mississippi embayment. Marine deposition during Miocene time is restricted to the Gulf Coast areas with one minor transgression occurring during the deposition of the *Heterostegina* zone.

INTRODUCTION

The present paper deals with the application of the principles of cyclic deposition to the Tertiary formations of the Mississippi embayment and the adjoining Gulf Coast area in Louisiana and Mississippi. These formations are well known from surface exposures, as well as numerous subsurface records, and they have been described in detail in many excellent publications. This available wealth of information made them a particularly favored object, not only for an application of the principles of cyclic deposition, but also for an application of its theory to stratigraphic and historical problems.

The more recent publications dealing with the Tertiary stratigraphy of Louisiana and Mississippi, and also the publications which were consulted in connection with other subjects discussed in this paper, are listed at its end.

PRINCIPLES OF MARINE CYCLIC DEPOSITION

Before discussing the sedimentary cycles of the Tertiary in the Mississippi embayment and the adjoining Gulf Coastal area, it may be in order to review first the principles of cyclic deposition upon which this study is based. The limited scope of the paper, however, will permit only a very brief and very generalized treatment of this subject.

Some of the principles of cyclic deposition have been discussed in a paper by

[1] Read before the Association at Chicago, April 3, 1946. Manuscript received, December 5, 1946.

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P. Arbenz (1) and they have been incorporated in the following attempt of a classification of marine depositional cycles.

The formation of marine sedimentary cycles is the result of repeated transgressions and regressions of the sea; these in turn are the result of diastrophic movements. The conception that such movements are responsible for marine transgressions and regressions forms the basic principle of this study and it is also used as such for the tentative classification of sedimentary cycles shown in Table I.

TABLE I
TENTATIVE CLASSIFICATION OF MARINE SEDIMENTARY CYCLES

DIASTROPHIC MOVEMENTS

A. AREAL EXTENT OF A DIASTROPHIC MOVEMENT

(a) Coast-line area→(b) Continental border area→(c) Continental area

↓ *Marine Sedimentary Cycles* ↓

TYPE I	TYPE II	TYPE III
Two-phase cycle:	Three-phase cycle:	Four-phase cycle:
Transgressive	Transgressive	Transgressive
Regressive	Inundative	Inundative
	Regressive	Regressive
		Continental

B. INTENSITY OF A DIASTROPHIC MOVEMENT

(a) Epeirogenic movement	(b) Orogenic movement
Marine Sedimentary Cycles	
Epeirogenic cycles: (Fine-clastic sediments)	Orogenic cycles: (Fine and coarse clastic sediments)

Minor diastrophic movements of relatively short duration affect mainly the depositional conditions along the shore line and coastal zones. If the diastrophic movements are more pronounced and extend over a longer period of time, they will affect the depositional conditions of the continental border areas, embayments, and intracontinental basins. In case of prolonged, widespread movements, depositional conditions over entire continents may be influenced. These three stages, reflecting the areal extent component of a diastrophic movement, produce three corresponding types of sedimentary cycles. In a marine cycle of Type I, resulting from shore-line oscillations, a transgressive and a regressive phase can usually be distinguished. In Type II, which is formed during extended invasion of the continental borderlands, an inundative phase appears between the transgressive and regressive phase, and in Type III, resulting from large scale invasions, a period of continental deposition may intervene between the marine regressive and transgressive phase.

Each phase of a sedimentary cycle has distinct lithologic characteristics, although considerable variations in the type of sediment may occur because the nature of the deposits is usually controlled more by local conditions and sources.

A transgressive phase may begin with a stage of lagoonal deposits, which grade laterally and vertically into shallow marine deposits (sands, marls, lime-

stones); or a basal conglomerate may be present. In general, the transgressive phase consists mainly of material reworked from the underlying formation or formations.

As it corresponds with a period of greatest advance of the sea, the inundative phase is characterized by a predominance of fine clastic sediments, such as shales and clays. These deposits are commonly interbedded with limestones and marls. Shoreward the inundative phase is replaced by a transgressive phase.

The regressive phase, formed during the retreat of the sea, generally contains coarser clastic material. Sandy deposits are interbedded with varying amounts of shales and lignites or calcareous sediments.

A diastrophic movement has also an intensity component. Using this criterion, it has been subdivided into epeirogenic and orogenic movements. Both types produce conditions of sedimentation which result in depositional cycles with characteristics clearly distinct from each other. Cycles formed during epeirogenic movements (in epicontinental areas) ordinarily have their cyclic phases well developed and they consist generally of a great variety of sediments. The phases in an orogenic sedimentary cycle, however, are less distinct and usually contain beds of coarse clastic material, such as breccias and conglomerates, especially in the transgressive and regressive phases. Sediments of an orogenic depositional cycle are known as Flysch deposits.

SEDIMENTARY CYCLES OF TERTIARY IN MISSISSIPPI EMBAYMENT

A generalized lithologic description of the Tertiary formations encountered on the surface and in the subsurface of Mississippi and Louisiana is shown in Figure 1.

Even a casual look at these descriptions brings out the fact that a repeated re-occurrence of certain lithologic groups or sequences is present in these formations. These lithologic repetitions indicate the cyclic deposition of the Tertiary beds in general. A single group consists of the following lithologic members. A marine series of calcareous or marl deposits, glauconitic sands, and dark shales, ordinarily containing an abundant and distinctive fauna, is overlain by a marine shale section, which grades upward into a series consisting of sands and sandstones, gray shales and lignites of shallow-marine or fluviatile origin.

By applying the phase principle of marine cyclic deposition to this sequence, it appears that the calcareous and glauconitic sand deposits represent the transgressive phase of a cycle, while the shale section represents the inundative phase and the overlying sand series forms the regressive phase. Therefore a sequence as described would represent one cycle of deposition, consisting of three phases. As shown in Figure 1, at least five such marine cycles can be recognized in the Tertiary section of the Mississippi embayment. A sixth cycle seems to be developed in the Miocene section of the Gulf Coast area. It displays a lithologic sequence very similar to the one found in the other cycles. It begins with the marine deposits of the *Heterostegina* zone and ends with the shallow-marine and

non-marine sands and clays of the upper Miocene and Pliocene. The marine part of this cycle, however, does not occur at the surface.

Since in all of these six cycles a more or less well developed inundative phase is present, they are considered to belong to Type II of the suggested classification. The first four cycles are, however, more characteristic of this type than the two latest ones, which approach Type I. Representing a Type II, these cycles are

Lithology	Formation: Mississippi	Formation: Louisiana	Group	Cycle: Phase	Cycle
Sand, shale, lignite	Catahoula + Post-Catahoula		Pliocene-Miocene	Regression	V
Dark shale	?	?		Inundation	
Limestone, marl, shale	Chickasawhay L. Byram Marl Marianna L. Forest Hill / Red Bluff	Vicksburg	Vicksburg (Oligocene)	Transgression	
Gray shale, marl	Yazoo	Jackson Shale	Jackson (Eocene)	Inundation	IV
Marl, glaucon sand	Moody's Branch	Moody's Branch		Transgression	
Sand, gray shale, lignite	Cockfield	Cockfield	Claiborne (Eocene)	Regression	III
Dark shale	Cook Mountain (Wautubee)	Cook Mountain Sh.		Inundation	
Limestone, shale, sand		Cook Mountain L.		Transgression	
Sand, shale, lignite	Sparta (Kosciusko)	Sparta		Regression	II
Dark shale	Zilpha	Cane River Sh.		Inundation	
Glauc. sand Marl, shale, glaucon sand	Winona Tallahatta	Cane River Marl		Transgression	
Sand, shale, lignite	Wilcox	Wilcox	Wilcox (Eocene)	Regression	I
Dark shale	Porter's Creek	Midway	Midway	Inundation	
Marl, calc. shale	Clayton			Transgression	
Upper Cretaceous					

FIG. 1.—Tertiary formations of Mississippi and Louisiana.

regarded as being formed during major invasions of the sea into the Mississippi embayment and central Gulf Coast area.

Within each of these major marine sedimentary cycles, minor cycles are present. They occur particularly in the regressive phases of the major cycles, reflecting minor shore-line oscillations during the general regressions of the sea. Mellen (17), and recently also Murray and Thomas (21), have noted and described cyclic deposition of the Wilcox beds in the Mississippi embayment, which seem to belong to this class. It is possible that such smaller cycles may be formed by causes other than diastrophic movements, and that they indicate merely changes in the depositional conditions, such as a shifting of deltaic distributaries.

The specific characteristics of the major cycles in the Mississippi embayment and central Gulf Coast area are: (1) the relatively poor development of the transgressive phase; (2) the presence of an impressive regressive phase and (3)

the considerable lithologic variations. These characteristics indicate that we are dealing with epeirogenic cycles of deposition.

The Jackson cycle is an exception to the foregoing statement that the regressive phases are well developed in the Tertiary sediments of the Mississippi embayment. This cycle has practically no regressive phase in this area, even if the Forest Hill and Red Bluff formations are considered to represent this phase, as is suggested by Mellen (18). The reason for this apparent exception is discussed later.

On the basis of paleontological data, it appears that a transition occurs from a regressive phase of one cycle to the transgressive phase of the following cycle, the general faunal characteristics being somewhat similar in both phases. Lithologically, a similar transition is noticeable between these two phases. The regressive phase, in its latest stage, becomes more marine in character and the transgressive phase actually represents the end stage of the marine transgression. In some places, however, a more abrupt change is found between the two phases, and minor unconformities may be present, separating the regressive phase from the transgressive phase. These unconformities become more apparent towards the edges of the embayment.

APPLICATION OF THEORY OF MARINE CYCLIC DEPOSITION

STRATIGRAPHIC PROBLEMS

It has been pointed out by other students of depositional cycles that their distinction can be used for a natural classification of sediments. As demonstrated in Figure 1, the present formational subdivision of the older Tertiary in Mississippi and Louisiana already follows closely the one suggested by the cyclic theory. Therefore, this theory finds little application in improving the classification of these particular sediments. However, a suggestion as to a different grouping of some of these formations presents itself. As the Midway and the Wilcox form a single marine depositional cycle, one may be justified to place them in one group instead of two as it is now customary. On the other hand, the Claiborne could be subdivided into a lower and an upper Claiborne group since two distinct major marine cycles apparently compose this formation. These changes are admittedly of minor importance.

Probably the most promising stratigraphic application of the cyclic theory is offered by the Oligocene-Miocene section encountered in the subsurface of the Gulf Coast area of Mississippi and Louisiana. The presence of two major marine cycles (V and VI) in this section, suggests two major subdivisions or groups, the first ranging from the Vicksburg to the base of the *Heterostegina* zone, the second ranging from the *Heterostegina* zone to the base of the Quaternary. So far, the Oligocene-Miocene subsurface section has been subdivided mainly on the basis of its microfaunas, and few attempts have been made to differentiate groups and formations. The cyclic theory offers a possible approach for such distinctions.

However, further discussion of this problem of classification will require additional research.

TECTONIC PROBLEMS

As the marine depositional cycles are considered to be the result of diastrophic movements, some idea about the structural history of the Mississippi embayment during Tertiary time may be gained by studying the thickness distribution of each cycle. Isopachous maps have been prepared for the first three cycles, which are reproduced in Figures 2, 3 and 4.

The thicknesses shown on these maps were all determined from electrical well logs and contouring was limited to areas where a sufficient number of such well records were available for close control. However, as only regional problems are under discussion, no attempt was made to reveal smaller, local isopachous anomalies on the maps.

Figure 2 shows the subsurface thickness of the Midway-Wilcox cycle in central and southern Mississippi, mapped on a 500-foot contour interval. By disregarding the thinning of section over the Jackson uplift in central Mississippi, three main areas can be recognized toward which a thinning of section takes place. One area is located in the northwest part of the map, another in the northeast part and the third appears in the extreme southeastern part of Mississippi. This arrangement creates two zones of maximum thickness. One zone trends east and west through southern Mississippi, extending into Alabama; the other trends approximately northeast and southwest, east of, and parallel with, the Mississippi River. Both of these zones merge in southwestern Mississippi. It may be noted that the maximum thickness of the Midway-Wilcox cycle in the east-west zone is still undetermined, since the one controlling well appears to have an abnormal section, as pointed out by McGlothlin (16, p. 53).

Figure 3 shows isopachs of the Cane River-Sparta cycle in Mississippi and Louisiana. As a considerably thinner section of sediments is involved in this cycle than in the preceding cycle, a 100-foot contour interval was used on this map. The thickness variations display a general pattern similar to that found for the Midway-Wilcox cycle, excepting that the area of thin section in southeast Mississippi has become enlarged on the north and northwest side, resulting in a shifting of the zones of maximum thicknesses to the north and northwest from their position during Midway-Wilcox time. The area of thin section, centering northeast of Alexandria, Louisiana, is an expression of the "LaSalle uplift," which is a more local structural feature in the central Gulf Coast.

Isopachs of the Cook Mountain-Cockfield cycle, shown in Figure 4, indicate a further enlargement of the area of thin section in southeast Mississippi with a corresponding north and northwest shifting of the two zones of maximum deposition.

Before attempting a structural interpretation of the isopachous maps, a brief discussion of the regional facies distribution of the Tertiary formations is neces-

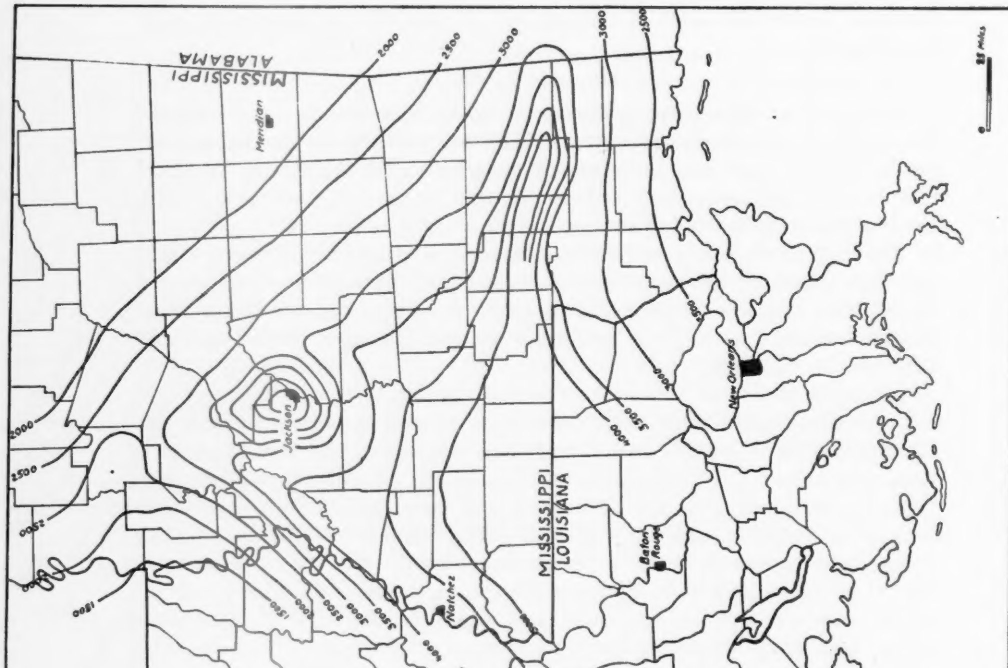


FIG. 2.—Isopachous map of Midway-Wilcox depositional cycle.

Fig. 2.—Isopachous map of Midway-Wilcox depositional cycle.

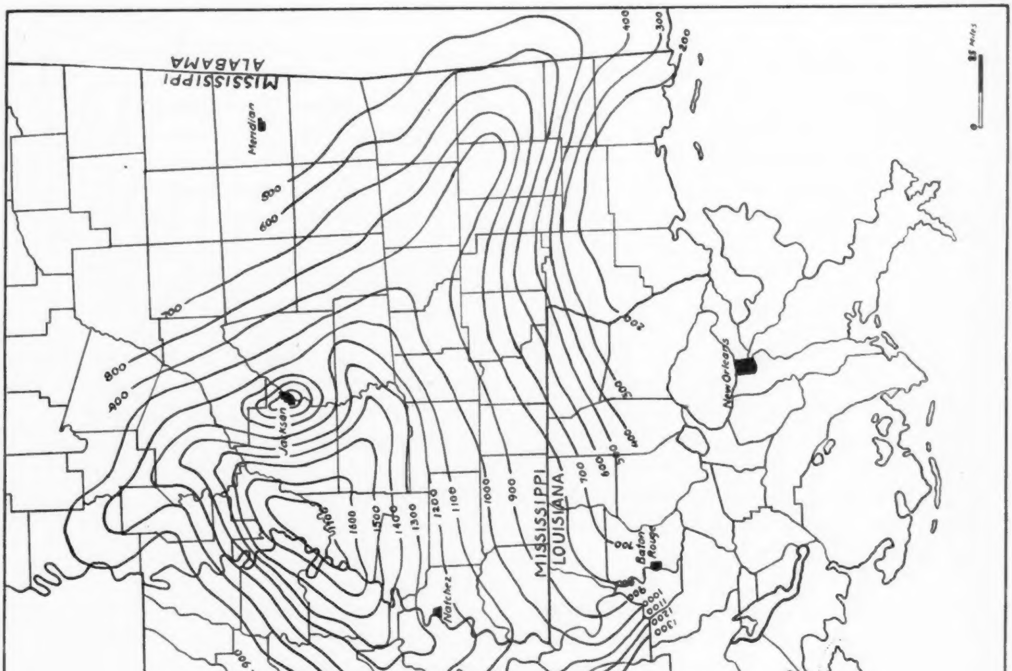


Fig. 3.—Isopachous map of Cane River-Sparta depositional cycle.

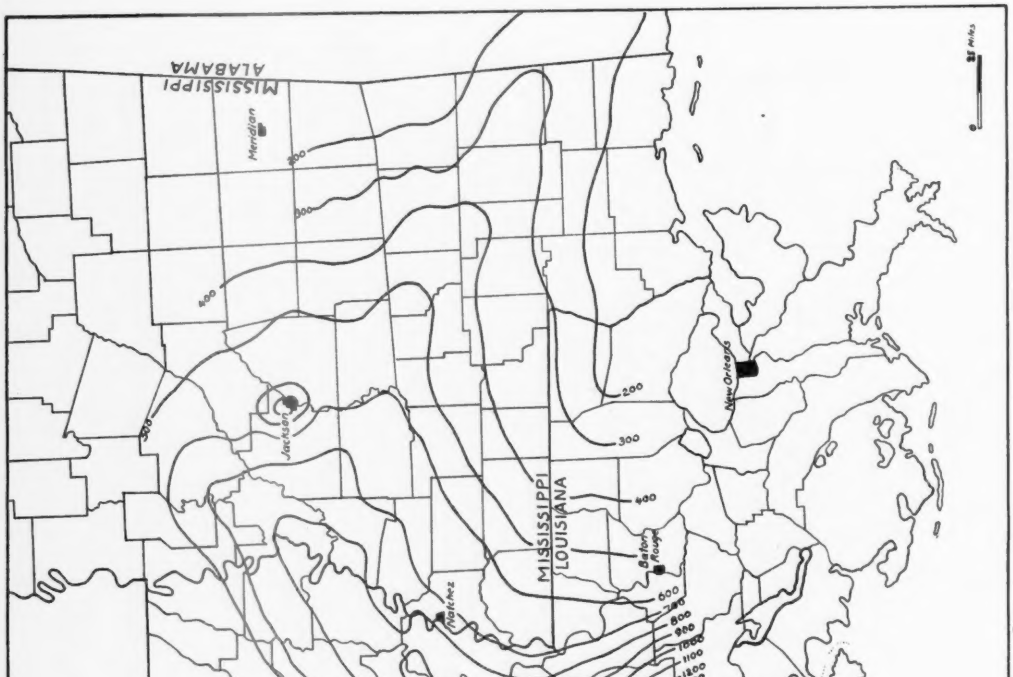


FIG. 4.—Isopachous map of Cook Mountain-Cockfield depositional cycle.

sary in order to interpret correctly the structural significance of thinning and thickening of section shown on these maps. This study reveals that in the Mississippi embayment proper, the Tertiary is developed predominantly in a sandy facies, consisting of shallow-marine and non-marine deposits. This sand facies grades into a marine shale facies generally southward toward the Louisiana Gulf Coast. In southern Louisiana, all Tertiary formations, with the exception of some upper Miocene-Pliocene beds, consist entirely or almost entirely of shale. This shale section reaches an estimated thickness of about 25,000–30,000 feet. In this lower Gulf Coast area, of course, a distinction of the depositional cycles of the Mississippi embayment and the interior Gulf Coast area becomes impossible. Here the shale section represents the inundative phase of a sedimentary cycle of higher order, comprising the entire Tertiary.

A facies change different from the one just described takes place southeastward toward the Mississippi Gulf Coast. In this direction the sand facies of the Mississippi embayment gradually changes into a marine limestone facies. This is particularly noticeable in formations younger than Wilcox, although the Midway and Wilcox, too, show a tendency to become more calcareous. As such calcareous deposits characterize submarine highs and plateaus, it is concluded that this limestone facies indicates the presence of a similar structural feature in southeast Mississippi. In a structural interpretation of the isopachous maps, the thin section encountered in this area can therefore be regarded as an expression of this submarine plateau. On the other hand, the thinning of section to the northeast and northwest appears to be normal shoreward thinning towards the borderlands of the Mississippi embayment, the formations becoming progressively more sandy and less marine in these directions. In the case of the northwest thinning, however, the decrease was accentuated by the presence of the Sharkey Platform, Monroe and Sabine Uplifts. The two zones of maximum thickness are interpreted to represent two synclinal trends, the one parallel to the Mississippi River reaching geosynclinal proportion in southern Louisiana where a maximum thickness of Tertiary sediments was deposited.

TERTIARY HISTORY

Although this study can add but few new facts to the discussion of the depositional history of the Mississippi embayment and adjoining areas by earlier authors, a brief summary of this history may be in order for a better understanding of the structural history.

Subsidence of the Mississippi embayment in connection with a general subsidence of the Gulf Coast area at the beginning of the Tertiary initiated the transgression of the Midway sea over these areas. This subsidence was most pronounced in the two synclinal trends mentioned, while the submarine plateau in southeast Mississippi remained more stable and acted as a positive structural element. As a result of this subsidence, the erosional forces in the bordering land areas, which undoubtedly experienced some uplift, were activated, and a con-

FIG. 4.—Isopachous map of Cook Mountain-Cockfield depositional cycle.

siderable amount of clastic material was transported into the sea by ancient rivers. According to Fisk (7, 8) and other students of Louisiana geology, this material was deposited largely as river deltas. More sediments seem to have been carried into the embayment from its western borderland, indicating that the compensating forces were more effective on this side than on the eastern borderland, which remained more stable during the entire Tertiary.

The filling of the embayment with clastic material, probably as a result of a diminished rate or complete cessation of subsidence, caused a general, slow retreat of the sea from the embayment during Wilcox time. This retreat, however, was interrupted by several minor advances of the sea. Rejuvenation of subsidence brought a new invasion during early Cane River time, which was followed by a filling of the newly created syncline during late Cane River and Sparta time, causing a second regression of the sea from the embayment. The same sequence of events took place during the Cook Mountain-Cockfield depositional cycle. However, the Cook Mountain invasion and also the preceding one, were evidently of considerably smaller regional extent than the Midway transgression. These two invasions seemed to have originated in the present Gulf Coast area, while the point of origin of the Midway transgression is still unknown. It may be located in the south part of the present Gulf of Mexico.

As illustrated by the isopachous maps, there is a noticeable progressive north and northwest shift of the two synclinal axes during earlier Eocene time. This shifting, which occurs in opposite direction to the general retreat of the sea, is apparently due to a corresponding enlargement of the submarine plateau of Southeast-Mississippi. The facies development and thickness distribution of the Jackson indicates that this plateau was further enlarged during this period so that it occupied the greater part of the mouth of the Mississippi embayment. The absence of a well developed regressive phase in the Jackson depositional cycle in Mississippi and Louisiana can be directly attributed to the presence of this submarine plateau. It created special conditions of sedimentation in this area which are characterized by a reduction or even total absence of clastic deposits and the replacement of clastic sediments by calcareous deposits. A thicker section of Jackson deposits is found in western Louisiana and a well developed regressive phase is present in the Texas Gulf Coast. This may indicate that the zone of maximum deposition shifted towards these areas in Jackson time.

Paleontological and stratigraphic data point to the possibility that some emergence has taken place after the close of Jackson deposition in the Mississippi embayment and the interior Gulf Coast area. This emergence, together with the "plugging" of the Mississippi embayment by the southeast Mississippi plateau, caused a retreat of the Gulf of Mexico from the embayment, and confined the later Vicksburg and upper Miocene (*Heterostegina* zone) marine transgressions to its southern border. However, even during these two latest invasions, the southeast Mississippi plateau remained, as evidenced by the predominantly calcareous character of the marine sediments deposited during the Oligocene and Miocene in

southern Mississippi and adjacent parts of Louisiana (Florida parishes).

In conclusion a few remarks may be added regarding the possible cause of the subsidence of the Mississippi embayment and its extension, the Gulf Coast geosyncline. Some authors have expressed the opinion that the weight of the sediments deposited in the embayment caused its subsidence and initiated the different transgressions of the Gulf of Mexico.[3]

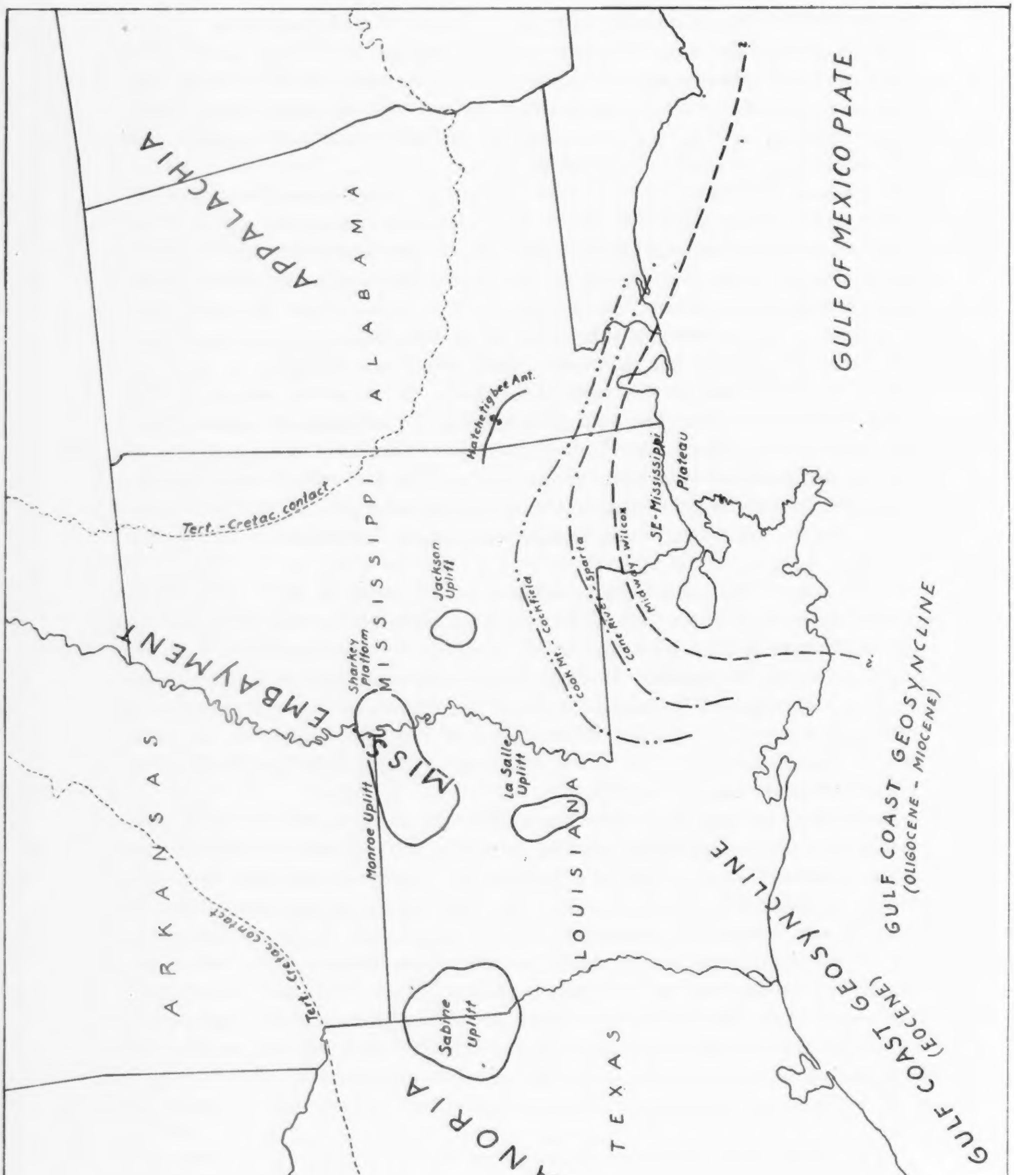
It has been previously stated that major marine transgressions are considered to be caused by diastrophic movements. As the Tertiary transgressions, discussed in this paper, are of major proportion affecting the entire northern border of the Gulf of Mexico, it is concluded that diastrophic movements are the primary cause of these transgressions. Since it is generally agreed that these Tertiary transgressions are the result of subsidence of the Mississippi embayment and the Gulf Coast geosyncline, the subsidence itself should be considered an effect of diastrophic movements. In the course of this study, the writer has not found clear evidence in support of the idea that the weight of the sedimentary column is the deciding factor for subsidence. On the contrary, all facts and evidences seem to point toward the conclusion that the formation of the Mississippi embayment is a tectonic incident closely related to the structural history of the Gulf of Mexico region, which underwent considerable epeirogenic movements during the Tertiary.

Confirming Suess' conclusions, Schuchert (23) believes that until recent geologic times the present Gulf of Mexico was occupied by an old landmass, the Gulf of Mexico neutral plate, which he considered to be the foreland of the orogenic zones of the Antilles. As the submarine plateau of southeast Mississippi was evidently separated by deeper synclines from the landmasses on the north and northwest, particularly during Midway-Wilcox time, it is possible that this plateau represents a part of the Gulf of Mexico plate, forming its northern border, at least during the earlier Tertiary.

In order to explain the progressive enlargment of the southeast Mississippi plateau and the corresponding shifting toward the north and northwest of its frontal synclinal zones during the Eocene, the theory is advanced that this plateau, together with the Gulf of Mexico plate, drifted in successive stages to the north as a result of Tertiary orogenic movements in the Antilles. A maximum penetration of the plateau into the Mississippi embayment was reached at the close of the Eocene and early Oligocene periods, when it touched the northern land masses. A breakdown of the southern part of this plateau and a large part of the Gulf of Mexico plate followed during the Oligocene and Miocene, forming the present Gulf of Mexico.[4] This downbreaking in connection with the emergence of the embayment, probably caused a change in direction of the Gulf Coast geo-

[3] For a more complete review of this subject the reader is referred to the paper by Storm (29).

[4] The Wiggins anticline of southern Mississippi (McGlothlin, 16, p. 29) is the present subsurface structural expression of the southeast Mississippi plateau. The southern Mississippi uplift, described by Fisk (7) is its present surface indication.


GULF OF MEXICO PLATE
APPALACHIA
ALABAMA
Hatchetigbee Ant.
MISSISSIPPI
SE-Mississippi Plateau
Midway - Wilcox
Cane River
Sparta
Cook Mt. - Cockfield
Jackson Uplift
Tert. - Cretac. contact
EMBAYMENT
Sharkey Platform
MISS.
Monroe Uplift
La Salle Uplift
ARKANSAS
LOUISIANA
Tert. - Cretac. contact
GULF COAST GEOSYNCLINE
(OLIGOCENE - MIOCENE)
Sabine Uplift
TEXAS
LLANORIA
GULF COAST GEOSYNCLINE
(EOCENE)

syncline in south Louisiana. During the Eocene, the axis of this syncline followed a southwest-northeast trend, with the Mississippi embayment syncline forming its northeastern extension. With the formation of the present Gulf of Mexico during Oligocene and Miocene time, this axis was diverted to a west-east trend (Fig. 5).

While the southeast Mississippi plateau drifted into the Mississippi embayment and approached the old Appalachian landmass, it can be reasonably speculated that some compressive forces may have been created between these two blocks. The initial formation of the Hatchetigbee anticline and similarly trending structures in southwestern Alabama may be attributed to such forces. Also, the zone of reversed faulting in Sumter and Marengo counties, Alabama, described by Monroe (19, p. 46), can be readily explained by this theory.

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STATUS OF MICROPALEONTOLOGY IN EASTERN GULF REGION[1]

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ABSTRACT

Since the paper by Finch in 1824, which initiated the study of the Cretaceous and Tertiary stratigraphy of the Eastern Gulf Region, more than 200 papers dealing with the microfossils of Mississippi, Tennessee, Alabama, Georgia, Florida, and South Carolina have appeared. Of these at least 160 deal primarily with Foraminifera, 21 with Ostracoda, 11 with Bryozoa, and 4 with otoliths. In these papers nearly 700 species of Foraminifera, 150 species of Ostracoda, 580 species of Bryozoa and 23 species of otoliths have been described as *new* in these states. Hundreds of other species whose type localities lie in other states or countries have been reported. The formations whose type localities have been reasonably thoroughly studied for their microfaunal content are indicated. Some suggestions of needed studies are made. The paper is accompanied by an annotated bibliography which lists the species which have been described as new in this region.

This paper is presented with the hope that it may assist the many geologists who have entered the Eastern Gulf Region for the first time to a quicker understanding of the problems of surface and subsurface correlation which are inherent in that region.

It is the region from which the framework of our American marine Tertiary stratigraphy has been developed. Papers dealing with the larger fossils of the Eastern Gulf Region are plentiful and date back to the work of John Finch (1824). Such is not the case with the microfossils. Although many Bryozoa had been described by Lea (1833), Conrad (1841) (1847), Tuomey and Holmes (1857), Holmes (1860), Gabb and Horn (1862), and deGregorio (1890), only a few of the larger Foraminifera, otoliths, and Ostracoda of this region were known prior to 1918.

The remarkable development of economic micropaleontology in the Gulf Coast centered largely in Houston. The incentive back of it was a need for subsurface information in the thick sections encountered in Louisiana and Texas, and the natural tendency of micropaleontologists was to go updip to the outcrop in those states for their fossils, rather than to come back to the type localities of the formations of the Eastern Gulf Region. Such procedure was not only natural, it was successful. The surface sediments of those states, particularly in the Tertiary, are thick sands and clays, many of them deltaic in origin. Many contain a microfauna unlike that encountered in the thinner limestone regions farther east.

The calcium carbonate content of the Eocene and Oligocene sediments increases steadily from the Mississippi eastward to South Carolina and the Florida peninsula. The same may be said of leaching. Commonly, the Foraminifera have been completely dissolved, yet ostracode carapaces remain intact. In places, leaching may have gone further, yet the Bryozoa of the limestones are quite fresh

[1] Read before the Association at Biloxi, Mississippi, October 24, 1946. Manuscript received, October 24, 1946.

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and usable. In this region, particularly in eastern Alabama, Georgia, Florida, and South Carolina, micropaleontologists may solve many of their problems of determination by resorting to the latter two groups. As the writer has pointed out in two recent papers (1942) (1943) a study of crinoid fragments, star-fish plates, ophiurians, and holothurians, if done systematically, might easily facilitate the recognition of certain horizons.

In a paper of this nature, with so much yet to be studied, it is simplest to summarize briefly the major work which has been published. The gaps in our knowledge of the microfaunal content of the type localities become obvious as the summary proceeds.

CRETACEOUS[3]

The first notice of Cretaceous microfossils appears to have been made by Bailey (1845) when he reported "Polythalmia" from Prairie Bluff and Selma, Alabama. This was followed by Ehrenberg's (1854) *Mikrogeologie* in which 47 species of Foraminifera were described from *"Schreib-Kreide des Mississippi-Gebietes."* The exact locality is unknown and as the figures were drawn with transmitted light, of specimens mounted in balsam, many are difficult to recognize. However, they can not be ignored, and after examining Ehrenberg's collections, Cushman (1927a) (1944f) has twice discussed the problem of what to do with Ehrenberg's species.

Systematic studies of Cretaceous Foraminifera by formations are limited to a few papers. Berry and Kelley (1929) described the Foraminifera of the Ripley on Coon Creek, Tennessee. Cushman (1931) gave a much more comprehensive report on the Cretaceous Foraminifera of Tennessee; and in (1944) described the Foraminifera of the Mooreville chalk of Mississippi. Lastly, Sandidge (1932a, b, c, d) in four papers described Ripley Foraminifera from Alabama.

Scattered species of Cretaceous Foraminifera are discussed or described by Applin and Applin (1944), Applin and Jordan (1945), Cole (1938–1945), Cushman (1926b) (1930c) (1941), Cushman and Applin (1945) (1946), Cushman and Parker (1935) (1936a), Cushman and Todd(1943), Vaughan and Cole (1932), and by Woodward (1894) (1898).

Other groups of microfossils have received scant attention in the Cretaceous of the Eastern Gulf Region, and workers will have to make comparison with forms described from other regions for their identifications.

MIDWAY EOCENE

The principal papers dealing with Midway Foraminifera of the Eastern Gulf Region are: one by Cushman (1940) describing a fauna from two localities within ½ mile of Livingston, Sumter County, Alabama; a paper by Cushman and Todd

[3] The writer wishes to call attention to J. A. Cushman (1946), "Upper Cretaceous Foraminifera of the Gulf Coastal Region of the United States and Adjacent Areas," *U. S. Geol. Survey Prof. Paper 206*, 241 pp., 66 pls. This is the most comprehensive monograph which has been published on American Foraminifera. Unfortunately, it did not reach the writer's hands until after this paper had been submitted for publication.

(1942a) on the Foraminifera of the Naheola formation; a later one by Cushman (1944) on the Foraminifera of the Coal Bluff member of the Naheola formation; and a report by Kline (1943) on the Midway Foraminifera and Ostracoda of Clay County, Mississippi.

Papers in which one or more Midway (or Cedar Keys) Foraminifera of this region are discussed or described are by Applin and Applin (1944), Applin and Jordan (1945), Cole (1938) (1944) (1945), Cushman (1926b), Cushman and Todd (1943), and Plummer (1938).

The few Midway Eocene Ostracoda described from the Eastern Gulf Region are to be found in papers by Howe (1934a), Stephenson (1938b), and Kline (1943).

The writer knows of no papers on Midway otoliths, but the Bryozoa were described by Canu and Bassler (1920) who list 54 species in this region.

WILCOX EOCENE

Three papers have been published on the Foraminifera of the Wilcox Eocene Bashi formation. They are by Cushman and Ponton (1932c), Cushman and Garrett (1939), and Cushman (1944a). The paper by Cushman and Garrett dealt with the region of the type locality. Toulmin (1941) described the Foraminifera of the Salt Mountain limestone. Garrett (1941) described a number of characteristic species of Wilcox Foraminifera.

Other papers in which Foraminifera are discussed or an occasional Wilcox species described are by Applin and Applin (1944), Applin and Jordan (1945), Cole (1938–1945), Cushman (1926b) (1927b), Cushman and Parker (1936b), Cushman and Garrett (1940), George and Bay (1935), Gravell and Hanna (1938), Hadley (1935), Toulmin (1940), and by Vaughan (1936).

There have been no papers describing Wilcox Ostracoda by formations in this region. However, Howe and Garrett (1934) give a checklist showing the range of certain species in the Wilcox of Alabama. Some species are described from the Wilcox of this region by Howe (1934a) and Stephenson (1938b). Murray and Hussey (1942) give a chart showing the range of the genus *Brachycythere* in the Wilcox of Alabama.

Wilcox otoliths are undescribed. Eleven species of Bryozoa were described from Woods Bluff, Alabama, by Canu and Bassler (1920).

CLAIBORNE EOCENE

Foraminifera were noted by Bailey from the vicinity of Claiborne Bluff as early as (1845). The only papers dealing primarily with Claiborne foraminiferal faunas are two recent ones by Cushman and Todd (1945) on the Lisbon at Claiborne Bluff and by Cushman and Herrick (1945) on the Foraminifera of the type locality of the McBean formation. Other papers in which some Claiborne Foraminifera of this region are described or discussed are by deGregorio (1890), Woodward (1894), Mossom (1926), Moberg (1928), Gravell and Hanna (1938) (1940), George and Bay (1935), Garrett (1941), Cushman and Ponton (1933),

Cushman and Todd (1942b), Cushman (1919a, b *middle Eocene considered Cretaceous*) (1926b) (1927a) (1939a), Cole (1938–1945), Applin and Applin (1944), and by Applin and Jordan (1945).

Some of the Claiborne Ostracoda have been described. Those which have been described from the Eastern Gulf Region are in papers by Murray (1938), Martin (1939), Stephenson (1942), Murray and Hussey (1942), and Swain (1946).

Six species of otoliths were described from the Claiborne of this region by Koken (1888), and refigured by Campbell (1929).

The Bryozoa of the Claiborne are covered by Canu and Bassler (1920). They list 26 species in the Claiborne of this region.

JACKSON EOCENE

Of all the Eocene foraminiferal faunas the Jackson has been most intensively studied. A paper by Cushman and Todd (1945b) is devoted to the type locality of the Moody's Branch marl. Another by Cushman (1945a) is devoted to the Twiggs clay. Three papers by Cushman (1925) (1928) (1946a) have been published on the Foraminifera of the so-called "Cocoa sand" of Alabama, but appear to have come from the clays above the Cocoa sand. Three papers by Cushman (1926c) (1933a) (1935a) are devoted to the description of Jackson Foraminifera largely of this region. Bergquist (1942) discussed with illustrations approximately 225 species and varieties of Jackson Foraminifera from Scott County, Mississippi, of which 9 were new. Monsour (1937) by means of a section and faunal lists gave the range of many of the described species in the Jackson of eastern Mississippi.

Other papers in which Jackson Foraminifera are described or discussed are by Applin and Applin (1944), Applin and Jordan (1945), Bailey (1845), Cole (1941–1945), Cushman (1917) (1920b) (1921b) (1924) (1926a, b) (1932b) (1936c) (1937a, b, c, d) (1939a) (1944b) (1945b), Cushman and Edwards (1938), Cushman and Garrett (1938), Cushman and Osawa (1930), Cushman and Todd (1944a), Fisk (1939), Garrett (1936), Gravell and Hanna (1935) (1938), Hadley (1935), Heilprin (1882) (1884) (1886), Howe (1934c), Mornhinveg (1941 *checklist*), Eugene A. Smith (1881), Vaughan (1928), Baughan and Cole (1936), and Vernon (1942).

The described species of Jackson Ostracoda are to be found in papers by Howe (1936), Howe and Chambers (1935), Murray and Hussey (1942), Meyer (1887), Stephenson (1936) (1937), and Swain (1946). A number of these are refigured by Bergquist (1942).

Sixteen species of otoliths were described by Koken (1888) which occur in the Jackson of this region. They were refigured by Campbell (1929) with a translation of Koken's descriptions.

More than 400 species of Bryozoa have been described from Jackson Eocene sediments. The majority of these species have been described from this region. They are comprehensively covered by Canu and Bassler (1920).

The abundance of comatulid crinoid remains in the sediments of the Jackson above the *Zeuglodon*-bed was pointed out by Howe (1942).

OLIGOCENE

The Oligocene has been studied more intensively than any other part of the column. The first Foraminifera described from this region was *Lepidocyclino mantelli* (Morton) (1833), who originally considered it to be a *Nummulites*. Numerous references to *Lepidocyclina* under various generic names in the stratigraphy of Mississippi, Alabama, and Florida are omitted from the present paper, but may be found in the papers which are listed in the bibliography.

The Oligocene Byram marl of Mississippi supplies a good illustration of the rapidity of change which is still taking place in foraminiferal literature. Cushman's (1922) paper, "The Byram Marl of Mississippi and Its Foraminifera," really marked the beginning of systematic studies of Gulf Coast Tertiary faunas at the type localities. In it he gave figures and descriptions of 60 species. Twenty more species were added by him in (1923); seven in (1929a, b); twelve in (1935); two in (1936c); and one in (1945b). Besides, additional species have been described from this locality by Cushman and Todd (1944a) and by Howe (1930a, b).

Contribution No. 280 from the Cushman Laboratory by Cushman and Todd (1946) also deals with the Foraminifera from the type locality of the Byram marl. In it 110 species of Foraminifera are discussed and in most cases illustrated, of which 16 species are described as new. A check with the original paper indicates that only 9 of the species reported in 1922 appear in this latest contribution with the same generic and specific names. Cushman and Todd suggest that the sample may have come from a part of the relatively short section different from the source of their previous samples. Part of the discrepancy, however, is to be accounted for by changes in generic nomenclature during the past 20 years; part by a closer scrutiny of species previously referred to living species, but in this report described as new.

A paper devoted to the Foraminifera of the Oligocene as a whole was published by Cushman (1923). Other papers dealing specifically with the Foraminifera of parts of the Oligocene are: Mint Spring marl by Cushman (1922c); Marianna limestone by Cole and Ponton (1930); Chickasawhay by Cushman and McGlamery (1938) (1939) (1942). Checklists of species present at type localities or well known sections have been published as follows: Red Bluff Oligocene at Hiwannee, Mississippi, by Howe (1928b); Red Bluff by Mornhinveg (1941); Glendon by Howe (1942a); Vicksburg, Mississippi, by Mornhinveg and Garrett (1935); Chickasaway of Wayne County, Mississippi, by Howe (1934d); Holmes and Washington counties, Florida, by Vernon (1942).

Additional Oligocene Foraminifera are described or discussed in papers by Applin and Applin (1944), Applin and Jordan (1945), Cole (1934) (1938) (1941) (1944) (1945), Conrad (1865), Cushman (1920a, b) (1926b) (1927b) (1930b) (1936c) (1937a, b, c) (1939a) (1944b) (1945b), Cushman and Edwards (1938), Cushman and Garrett (1938), Cushman and Hanzawa (1937), Cushman and Ozawa (1930), Cushman and Parker (1936b) (1937), Cushman and Todd (1942b)

(1943) (1944a), Ellis (1939), George and Bay (1935), Gravell and Hanna (1938), de Gregorio (1890), Hadley (1935), Howe (1928a) (1934c), Mansfield (1939), Moberg (1928), Stuckey (1946), Vaughan (1933), and by Vaughan and Cole (1936).

Descriptions of Oligocene Ostracoda of this region may be found in paper by Coryell, Sample and Jennings (1935), Howe (1934a, b) (1936), Howe and Law (1936), Murray and Hussey (1942), Stephenson (1936) (1937) (1946), and Swain (1946).

Six species of otoliths were described as occurring in the Oligocene by Koken (1888) and were refigured by Campbell (1929). Canu and Bassler (1920), in their comprehensive report, describe nearly 200 species of Bryozoa from the Oligocene of this region. McGuirt (1934) published a checklist of the Bryozoa of the lower Chickasawhay, and Howe (1942a) of the type locality of the Glendon. The presence of ophiurians, comatulid crinoids, starfish, and holothurians of potential value in the Oligocene of this region was pointed out by Howe (1942).

MIOCENE

The first Miocene species of Foraminifera to be described from Florida were *Archaias floridanus* and *Cristellaria rotella* by Conrad (1846). They were from the lower Miocene Tampa limestone, which Conrad at that time considered to be Eocene. Bailey (1851) also discussed the Foraminifera of the Tampa, but did not describe any species. The Foraminifera of the Tampa have received but little attention since that time.

The larger papers dealing with the Miocene Foraminifera of this region are by Cushman (1918) (1930a), Cushman and Cahill (1933), and Cushman and Ponton (1932a). Other Miocene species of Foraminifera are described or discussed in papers by Cole (1938) (1941) (1945), Cushman (1919b) (1921a) (1929c, d) (1932a) (1937a, b, c) (1939a) (1944b) (1946b, c), Cushman and Ozawa (1930), Cushman and Ponton (1931a, b) (1932b), Cushman and Todd (1941) (1942b) (1944a, b), Ellis (1939), Gravell and Hanna (1938), Howe (1934d), Mincher (1941), R. Hendee Smith (1941), and Vernon (1942).

Descriptions of Miocene Ostracoda of this region are to be found in papers by Howe (1934a), Howe and graduate students (1935), Mincher (1941), Smith (1941), and by Stephenson (1938a) (1941a). Many additional upper Miocene species which occur in Florida may be found also in Edwards' (1944) paper on the Ostracoda of the Duplin marl of North Carolina, and some others in Van den Bold's large report on the microfauna of the Caribbean Region (1946). Lists of species from certain localities in Holmes and Washington counties, Florida, are given by Vernon (1942). Most species described to date, however, have come from the middle and upper Miocene.

The Bryozoa of the Miocene are well covered by Canu and Bassler (1923). A checklist of those which occur in the upper Chickasawhay of Mississippi may be found in McGuirt (1934).

PLIOCENE AND PLEISTOCENE

Papers dealing with Pliocene and Pleistocene Foraminifera of this region have been published by Cushman (1918) and Cole (1931). Foraminiferal lists by Cushman for the region of southern Mississippi are given in the paper by Brown, Foster, Adams, Reed, and Padgett (1944). Pliocene and Pleistocene Foraminifera are closely related to those living off the Florida coasts to-day, which were described by Cushman (1922a).

Pliocene ostracode species belonging to the genus *Cytheridea* were described by Stephenson (1938a), but species of the other genera are yet unstudied. The Bryozoa have been described by Canu and Bassler (1923).

CONCLUSION

In a paper of this scope some articles perhaps have been overlooked. This is doubly true when fully half of the reports in which Foraminifera of this region are described bear nothing in their title to indicate that they deal with the states under discussion. Most of the papers of a systematic nature do not have an index and the species described from this region may be located only by turning pages. The accompanying bibliography of more than 200 titles, however, is believed to be sufficiently complete to supply the essential reference material for the economic paleontologists and geologists whose work lies in this region. To make the bibliography more useful it is annotated to indicate the presence of checklists and in most cases the names of the species whose type localities lie within the boundaries of the states under consideration.

It is obvious that most paleontologists do not possess personal copies of many of the publications listed, nor are they available in company district offices. Identifications and correlations can be only as accurate as the information on which they are based. The August issue of the *Bulletin* of our Association supplies a comprehensive list of the libraries in this country which are prepared to supply film copies of rare publications. Is it asking too much to expect the major companies to place film copies with a microfilm reader in their district offices?

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sis, Planulina cedarkeysensis, Linderina floridensis, Lepidorbitoides (Lepidorbitoides) floridensis, L. (Pliolepidina) cedarkeysensis.]

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——— (1921b), "American Species of *Operculina* and *Heterostegina*," *U. S. Geol. Survey Prof. Paper 128-E*, pp. 125–37, Pls. 18–21. [New: *Operculina cookei, O. vaughani, O. ocalana, Heterostegina ocalana* and var. *glabra.*]

——— (1922a) "Shallow-Water Foraminifera of the Tortugas Region," Publ. 311, *Carnegie Inst. Washington Pub. 311*, Vol. 17. 85 pp., 14 pls. [Recent Foraminifera of the Florida coast.]

——— (1922b), "The Byram Calcareous Marl of Mississippi and its Foraminifera," *U. S. Geol. Survey Prof. Paper 129-E*. 43 pp., 15 pls. [New: *Textularia tumidulum, T. subhauerii, T. mississippiensis, Bolivina mississippiensis, Verneuilina spinulosa glabrata, Clavulina byramensis, Ehrenbergina glabrata, Polymorphina byramensis, Discorbis byramensis, Truncatulina pseudoungeriana, Anomalina bilateralis, A. mississippiensis, Pulvinulina byramensis, P. advena, P. glabrata, Rotalia*

byramensis, Asterigerina subacuta, Spiroloculina byramensis, S. imprimata, Vertebralina advena, Articulina byramensis, Massilina crusta, M. occlusa, M. occlusa costulata.]

——— (1922c), "The Foraminifera of the Mint Spring Calcareous Marl Member of the Marianna Limestone," *U. S. Geol. Survey Prof. Paper 129-E.* 30 pp., 7 pls. [New: *Bolivina cookei, B. vicksburgensis, B. frondea, Verneuilina rectimargo, Buliminella subteres angusta, Lagena orbignyana flintii, Cristellaria vicksburgensis, Polymorphina advena, P. cuspidata costulata, P. vicksburgensis, Spirillina limbata bipunctata, Patellina advena, Truncatulina vicksburgensis, Anomalina vicksburgensis, Rotalia dentata parva, R. vicksburgensis, Nonionina advena, Quinqueloculina cookei, Q. vicksburgensis, Q. glabrata, Q. lustra, Q. tessellata, Massilina decorata, Triloculina peroblonga, T. sculpturata.*]

——— (1923), "The Foraminifera of the Vicksburg Group," *U. S. Geol. Survey Prof. Paper 133*, pp. 11–71, Pls. 1–8. [New: *Textularia mississippiensis alabamensis, T. recta, Bolivina depressula, B. caelata, B. caelata byramensis, Gaudryina advena, Clavulina byramensis extans, C. byramensis turgida, Bulimina sculptilis, Pavonina advena, Lagena cookei, Cristellaria vicksburgensis apena, Polymorphina regina rutila, Discorbis eximius, Pulvinulina mariannensis, Rotalia advena, Quinqueloculina byramensis.*]

——— (1924), "A New Genus of Eocene Foraminifera," *Proc. U. S. Nat. Mus.*, Vol. 66, pp. 1–4, Pls. 1,2. [New: *Hantkenina alabamensis.*]

——— (1925), "Eocene Foraminifera from the Cocoa Sand of Alabama," *Contrib. Cushman Lab. Foram. Res.*, Vol. 1, Pt. 3, No. 16, pp. 65–68, Pl. 10. [New: *Nodosaria cocoaensis, Cristellaria gutticostata cocoaensis, Marginulina cocoaensis, Uvigerina jacksonensis, U. cocoaensis.*]

——— (1926a), "*Trifarina* in the American Eocene and Elsewhere," *Contrib. Cushman Lab. Foram. Res.*, Vol. 1, Pt. 4, No. 19, pp. 86–88. [New: *Trifarina bradyi advena.*]

——— (1926b), "The Genus *Lamarckina* and Its American Species," *Contrib. Cushman Lab. Foram. Res.*, Vol. 2, Pt. 1, No. 24, pp. 7–13, Pl. 1. [New: *Lamarckina ripleyensis, L. wilcoxensis, L. marylandica claibornensis, L. ocalana.*]

——— (1926c), "Some New Foraminifera from the Upper Eocene of the Southeastern Coastal Plain of the United States," *Contrib. Cushman Lab. Foram. Res.*, Vol. 2, Pt. 2, No. 27, pp. 29–36, Pl. 4. [New: *Textularia adalta, Textularia ocalana, Bolivina attenuata, B. spiralis, B. gardnerae, Bifarina dalli, Buliminella alabamensis, Vulvulina advena, Gaudryina jacksonensis, G. gardnerae, Verneuilina sculptilis, Valvulina ocalana, Bulimina jacksonensis cuneata, Polymorphina jacksonensis, P. jacksonensis costifera.*]

——— (1927a), "The Occurrence of *Lituonella* and *Coskinolina* in America," *Jour. Washington Acad. Sci.*, Vol. 17, No. 8, pp. 198, 199. [Occurrence in Eocene of Florida.]

——— (1927b), "Foraminifera of the Genus Siphonina and Related Genera," *Proc. U. S. Nat. Mus.* Vol. 72, Art. 20, pp. 1–15, Pls. 1–4. [New from this region: *Siphonina wilcoxensis, S. claibornensis.*]

——— (1927c), "The American Cretaceous Foraminifera Figured by Ehrenberg, *Jour. Paleon.*, Vol. 1, No. 3, pp. 213–17, Pls. 34–36.

——— (1928), "Additional Foraminifera from the Upper Eocene of Alabama," *Contrib. Cushman Lab. Foram. Res.*, Vol. 4, Pt. 3, No. 64, pp. 73–79, Pl. 10. [New: *Eponides cocoaensis, Globorotalia cocoaensis, Anomalina cocoaensis, Planulina cocoaensis.*]

——— (1929a), "The Genus *Bolivinella* and Its Species," *Contrib. Cushman Lab. Foram. Res.*, Vol. 5, Pt. 2, No. 75, pp. 28–34, Pl. 5. [New: *Bolivinella subpectinata.*]

——— (1929b), "Notes on the Foraminifera of the Byram Marl," *Contrib. Cushman Lab. Foram. Res.*, Vol. 5, Pt. 2, No. 77, pp. 40–48, Pls. 7, 8. [New: *Lagena byramensis, Buliminella obtusata, Loxostomum amygdalaeformis delicata, Tubulogenerina aperta, Siphoninella byramensis, Asterigerina bracteata.*]

——— (1929c), "An American *Virgulina* Related to *V. pertusa* Reuss," *Contrib. Cushman Lab. Foram. Res.*, Vol. 5, Pt. 2, No. 78, pp. 53, 54, Pl. 9. [New: *Virgulina floridana.*]

——— (1929d), "*Virgulina gunteri* Cushman—A Correction of Name," *Contrib. Cushman Lab. Foram. Res.*, Vol. 5, Pt. 4, No. 86, p. 105.

——— (1930a), "The Foraminifera of the Choctawhatchee Formation of Florida," *Florida Geol. Survey Bull. 4*, pp. 1–89, Pls. 1–12. [New: *Urnulina compressa, Pseudarcella arenata, Nonion glabrella, Plectofrondicularia floridana, Bulimina gracilis, Virgulina fusiformis, Bolivina plicatella, B. pulchella primitiva, Loxostomum gunteri, Valvulineria floridana, Eponides mansfieldi, Pulvinulinella pontoni, Ellipsolagena bidens.*

——— (1930b), "Some Notes on the Genus *Patellina*," *Contrib. Cushman Lab. Foram. Res.*, Vol. 6, Pt. 1, No. 88, pp. 11–17, Pl. 3.

——— (1930c), "Notes on Upper Cretaceous Species of *Vaginulina, Flabellina* and *Frondicularia* from Texas and Arkansas," *Contrib. Cushman Lab. Foram. Res.*, Vol. 6, Pt. 2, No. 90, pp. 25–38, Pls. 4, 5. [New: *Vaginulina multicostata*, from Alabama.]

——— (1931), "A Preliminary Report on the Foraminifera of Tennessee," Tennessee Div. Geol. *Bull. 41*, pp. 1–116, Pls. 1–13. [New: *Frondicularia glabrans, F. cuspidata, Nonionella cretacea, Guembelina spinifera, Spiroplectoides papillata, Eouvigerina hispida, Pseudouvigerina cretacea,*

Bolivina tenuis selmaensis, Loxostoma plaitum limbosum, Cassidulina cretacea, Robulus pondi, Dentalina legumen spirans.]

——— (1932a), "Notes on the Genus *Virgulina*," *Contrib. Cushman Lab. Foram. Res.*, Vol. 8, Pt. 1, No. 118, pp. 7–23, Pls. 2, 3. [New: *V. pontoni.*]

——— (1932b), "The Genus *Vulvulina* and Its Species," *Contrib. Cushman Lab. Foram. Res.*, Vol. 8, Pt. 4, No. 123, pp. 75–85, Pl. 10. [Figures and redescriptions of Eastern Gulf species.]

——— (1932c), "*Textularia* and Related Forms from the Cretaceous," *Contrib. Cushman Lab. Foram. Res.*, Vol. 8, Pt. 4, No. 124, pp. 86–97, Pl. 11. [Revision of a number of Eastern Gulf species.]

——— (1933a), "New Foraminifera from the Upper Jackson Eocene of the Southeastern Coastal Plain Region of the United States," *Contrib. Cushman Lab. Foram. Res.*, Vol. 9, Pt. 1, No. 127, pp. 1–21, Pls. 1, 2. [New: *Gaudryina subquadrata, Miliola jacksonensis, Massilina jacksonensis, M. jacksonensis punctato-costata, Articulina terquemi, Robulus gutticostatus yazooensis, R. arcuato-striatus carolianus, Saracenaria arcuata hantkeni, Nodosaria latejugata carolinensis, Planularia cooperensis, Marginulina cooperi, M. cooperensis, Dentalina cooperensis, D. halkyardi, D. hantkeni, Nodosaria cookei, Lagena orbignyana semiconcentrica, Nonionella jacksonensis, Sprioplectoides curta, Plectofrondicularia cookei, Nodogenerina cooperensis, Bulimina cooperensis, Virgulina recta, Reussia eocena, Uvigerina glabrans, U. yazooensis, Angulogerina ocalana, Discorbis globulospinosa, D. ocalana, D. assulata, D. alabamensis, D. alveata, D. bulla, Eponides ocalana, E. minima, Valvulineria jacksonensis, Lamarckina jacksonensis, Planulina cocoaensis cooperensis, Cibicides cooperensis, Rupertia (?) floridana.*]

——— (1933b), "New American Cretaceous Foraminifera," *Contrib. Cushman Lab. Foram. Res.*, Vol. 9, Pt. 3, No. 134, pp. 49–64, Pls. 5–7. [New: *Gaudryinella capitosa, Heterostomella cuneata curvata, Goësella rugulosa, Dorothia pontoni, Bolivinita selmensis;* from Miss. and Tenn.]

——— (1935a), "Upper Eocene Foraminifera of the Southeastern United States," *U. S. Geol. Survey Prof. Paper 181*, pp. i, ii, 1–88, Pls. 1–23. [New from this region: *Massilina cookei, Marginulina karreriana, Angulogerina cooperensis, Gyroidina orbicularis planata, Eponides carolinensis, E. budensis planata, Cibicides mississippiensis ocalanus, Carpenteria carolinensis, Uvigerina cookei.*]

——— (1935b), "*Bitubulogenerina howei*, a New Species from the Lower Oligocene" [of Mississippi], *Contrib. Cushman Lab. Foram. Res.*, Vol. 11, Pt. 1, No. 155, pp. 20–21, Pl. 3, Figs. 10–12.

——— (1935c), "New Species of Foraminifera from the Lower Oligocene of Mississippi," *Contrib. Cushman Lab. Foram. Res.*, Vol. 11, Pt. 2, No. 156, pp. 25–39, Pls. 4, 5. [New: *Triloculina mississippiensis, Massilina glabricostata, Flintia laticoncava, Pyrgo oligocenica, Cornuspira byramensis, Planispirina mornhinvegi, Spirolina arrecta, Frondicularia garretti, Entosolenia crumenata, E. byramensis, Nonionella crassipunctata, N. pauciloba, Bolivina mornhinvegi, B. garretti, Angulogerina vicksburgensis, A. rugoplicata, Spirillina vicksburgensis, Valvulineria paucilocula, V. sculpturata, Discorbis subglobosa, D. arcuato-costata, Heronallenia vicksburgensis.*]

——— (1936a), "Some American Cretaceous Species of *Ellipsonodosaria* and *Chrysalogonium*," *Contrib. Cushman Lab. Foram. Res.*, Vol. 12, Pt. 3, No. 172, pp. 51–55, Pl. 9. [New from Tenn.: *Ellipsonodosaria horridens.*]

——— (1936b), "Cretaceous Foraminifera of the Family Chilostomellidae," *Contrib. Cushman Lab. Foram. Res.*, Vol. 12, Pt. 4, No. 175, pp. 71–78, Pl. 13. [New from Tennessee: *Pullenia cretacea.*]

——— (1936c), "New Genera and Species of the Families Verneuilinidae and Valvulinidae of the Subfamily Virgulininae," *Cushman Lab. Foram. Res. Spec. Pub. 6*, pp. 1–71, Pls. 1–8. [New from this region: *Pseudoclavulina cocoaensis, Virgulina vicksburgensis, Bolivina mississippiensis costifera.*]

——— (1937a), "A Monograph of the Foraminiferal Family Verneuilinidae," *Cushman Lab. Foram. Res. Spec. Pub. 7*, pp. i–xiii, 1–157, Pls. 1–20.

——— (1937b), "A Monograph of the Foraminiferal Family Valvulinidae," *Cushman Lab. Foram. Res. Spec. Pub. 8*, pp. i–xiii, 1–210, Pls. 1–24.

——— (1937c), A Monograph of the Subfamily Virgulininae of the Foraminiferal Family Buliminidae," *Cushman Lab. Foram. Res. Spec. Publ 9*, pp. i–xv, 1–228, Pls. 1–24.

——— (1937d), "The Described American Eocene Species of *Uvigerina*," *Contrib. Cushman Lab. Foram. Res.*, Vol. 13, Pt. 3, No. 188, pp. 74–87, Pls. 11, 12.

——— (1937e), "Some Notes on Cretaceous Species of *Marginulina*," *Contrib. Cushman Lab. Foram. Res.*, Vol. 13, pt. 4, No. 189, pp. 91–99, Pls. 13, 14. [New from Alabama: *Marginulina navarroana.*]

——— (1938a), "A Few New Species of American Cretaceous Foraminifera," *Contrib. Cushman Lab. Foram. Res.*, Vol. 14, Pt. 1, No. 190, pp. 100–05, Pl. 15. [New from Tennessee: *Vagniulina selmaensis.*]

——— (1938b), "Cretaceous Species of *Gumbelina* and Related Genera," *Contrib. Cushman Lab. Foram. Res.*, Vol. 14, Pt. 1, No. 193, pp. 2–28, Pls. 1–4.

——— (1938c), "Additional New Species of American Cretaceous Foraminifera," *Contrib. Cushman Lab. Foram. Res.*, Vol. 14, Pt. 2, No. 195, pp. 31–50, Pls. 5–8. [New from this region: *Dentalina basitorta, D. solvata, D. pertens, Ramulina globo-rubulosa, Nonionella ansata.*]

——— (1938d), "Some New Species of Rotaliform Foraminifera from the American Cretaceous,"

Contrib. Cushman Lab. Foram. Res., Vol. 14, Pt. 3, No. 198, pp. 66–71, Pls. 11, 12. [New: *Globotruncana cretacea, Anomalina semicomplanta, Cibicides stephensoni, C. berryi* (new name).]

——— (1939a), "A Monograph of the Foraminiferal Family Nonionidae," *U. S. Geol. Survey Prof. Paper 191*, pp. 1–100, Pls. 1–20. [Reviews described Eastern Gulf species.]

——— (1939b), "New American Cretaceous Foraminifera," *Contrib. Cushman Lab. Foram. Res.*, Vol. 15, Pt. 4, No. 212, pp. 89–93, Pl. 16. [New from Tennessee: *Robulus stephensoni, Globotruncana cretacea.*]

——— (1940a), "American Upper Cretaceous Foraminifera of the Family Anomalinidae," *Contrib. Cushman Lab. Foram. Res.*, Vol. 16, Pt. 2, No. 218, pp. 27–40, Pls. 5–7.

——— (1940b), "Midway Foraminifera from Alabama," *Contrib. Cushman Lab. Foram. Res.*, Vol. 16, Pt. 3, No. 222, pp. 51–73, Pls. 9–12. [New: *Ammobaculites midwayensis, Dorothia alabamensis, Listerella laevis, Dentalina plummerae, Frondicularia midwayensis, Gümbelina midwayensis, Rectogümbelina alabamensis, Eouvigerina excavata, Ellipsonodosaria plummerae, Discorbis midwayensis.*]

——— (1940c), "American Upper Cretaceous Foraminifera of the Genera *Dentalina* and *Nodosaria*," *Contrib. Cushman Lab. Foram. Res.*, Vol. 16, Pt. 4, No. 223, pp. 75–96, Pls. 13–16.

——— (1941), "American Upper Cretaceous Foraminifera Belonging to *Robulus* and Related Genera," *Contrib. Cushman Lab. Foram. Res.*, Vol. 17, Pt. 3, No. 230, pp. 55–69, Pls. 15, 16.

——— (1944a), "A Foraminiferal Fauna of the Wilcox Eocene, Bashi Formation, from Near Yellow Bluff, Alabama," *Amer. Jour. Sci.*, Vol. 242, pp. 7–18, Pls. 1, 2. [New: *Dentalina wilcoxensis, Guttulina problema arcuata.*]

——— (1944b), "The Genus *Articulina* and Its Species," *Cushman Lab. Foram. Res. Spec. Pub. 10.* 21 pp. 4 pls. [New from this region: *Articulina jacksonensis, A. paucicostata.*]

——— (1944c), "A Paleocene Foraminiferal Fauna from the Coal Bluff Marl Member of the Naheola Formation of Alabama," *Contrib. Cushman Lab. Foram. Res.*, Vol. 20, Pt. 2, No. 255, pp. 29–50, Pls. 5–8. [New: *Textularia midwayana pansa, Quinqueloculina pulcherrima, Q. alabamensis, Spiroloculina alabamensis, Triloculina natchitochensis deca, T. alabamensis, Robulus alabamensis, Planularia toddae, Marginulina toulmini, Dentalina alabamensis, D. eocenica, Nodosaria macneili, Lingulina minuta, Virgulina alabamensis, Parella macneili.*]

——— (1944d), "*Virgulina naheolensis*, New Name," *Contrib. Cushman Lab. Foram. Res.*, Vol. 20, Pt. 3, No. 261, p. 78.

——— (1944e), "Foraminifera of the Lower Part of the Mooreville Chalk of the Selma Group of Mississippi," *Contrib. Cushman Lab. Foram. Res.*, Vol. 20, Pt. 4, pp. 83–96, Pls. 13, 14. [New: *Pseudoglandulina costulata.*]

——— (1944f), "Additional Notes on Foraminifera in the Collection of Ehrenberg," *Jour. Washington Acad. Sci.*, Vol. 34, No. 5, pp. 157–158.

——— (1945a), "A Foraminiferal Fauna from the Twiggs Clay of Georgia," *Contrib. Cushman Lab. Foram. Res.*, Vol. 21, Pt. 1, No. 265, pp. 1–11, Pls. 1, 2. [New: *Proteonina eocenica, P. prolixa, Millettella eocenica, M. elongata, Nonion whitselatense insuetum, Elphidium twiggsanum, E. fastigiatum, Elphidioides americanus, Virgulina minutissima, Valvulineria georgiana compacta, V. jacksonensis dentata, Cassidulina twiggsana, Cibicides praeconcentricus.*]

——— (1945b), "The Species of the Subfamily Reussellinae of the Foraminiferal Family Buliminidae," *Contrib. Cushman Lab. Foram. Res.*, Vol. 21, Pt. 2, No. 267, pp. 23–54, Pls. 5–8. [New from this region: *Reussella miocenica, R. rectimargo hebetata, Chrysalidinella micoenica.*]

——— (1946a), "A Rich Foraminiferal Fauna from the Cocoa Sand of Alabama," *Cushman Lab. Foram. Res. Spec. Pub. 16.* 40 pp., 8 pls. [New: *Spiroplectammina mississippiensis distincta, Karreriella lalickeri, Robulus inusitatus, Marginulina lalickeri, Dentalina cooperensis gracilescata, Bolivina gracilis incisurata, B. alazanensis primaeva, Cancris cocoaensis, Cassidulinoides howei.*]

——— (1946b), "The Genus *Hauerina* and Its Species," *Contrib. Cushman Lab. Foram. Res.*, Vol. 22, Pt. 1, No. 274, pp. 2–15, Pls. 1–2.

——— (1946c), "The Genus *Sigmoilina* and Its Species," *Contrib. Cushman Lab. Foram. Res.*, Vol. 22, Pt. 2, No. 276, pp. 29–45, Pls. 5, 6. [New from Florida: *Sigmoilina miocenica.*]

CUSHMAN, J. A., AND APPLIN, ESTHER R. (1945), "A New *Pseudoclavulina* from the Upper Cretaceous of Alabama," *Contrib. Cushman Lab. Foram. Res.*, Vol. 21, Pt. 3, No. 270, p. 74, Pl. 12, f. 4, 5. [New: *P. moorevillensis.*]

——— (1946), "Some Foraminifera of Woodbine Age from Texas, Mississippi, Alabama, and Georgia," *Contrib. Cushman Lab. Foram. Res.*, Vol. 22, Pt. 3, No. 279, pp. 71–76, Pl. 13. [New from this region: *Ammobaculites braunsteini.*]

CUSHMAN, J. A., AND CAHILL, E. D. (1933), "Miocene Foraminifera of the Coastal Plain of the Eastern United States," *U. S. Geol. Survey Prof. Paper 175-A*, pp. 1–50, Pls. 1–13, table. [Illustrates and describes many species of the Eastern Gulf Region.]

CUSHMAN, J. A., AND EDWARDS, PATRICIA G. (1938), "Notes on the Oligocene Species of *Uvigerina* and *Angulogerina*," *Contrib. Cushman Lab. Foram. Res.*, Vol. 14, Pt. 4, No. 200, pp. 74–89.

CUSHMAN, J. A., AND GARRETT, J. B. (1938), "Three New Rotaliform Foraminifera from the Lower Oligocene and Upper Eocene of Alabama," *Contrib. Cushman Lab. Foram. Res.*, Vol. 14, Pt. 3, No. 197, pp. 62–66, Pl. 11. [New: *Discorbis cocoaensis, Cibicides pippeni, C. cookei.*]

——— (1939), "Eocene Foraminifera of Wilcox Age from Woods Bluff, Alabama," *Contrib. Cushman Lab. Foram. Res.*, Vol. 15, Pt. 4, No. 211, pp. 77–89, Pls. 13–15. [New: *Darbyella wilcoxensis, Uvigerina wilcoxensis, U. alabamensis, Asterigerina wilcoxensis, A. alabamensis.*]

——— (1940), *Asterigerina tombigbeensis* Cushman and Garrett, a New Name," *Contrib. Cushman Lab. Foram. Res.*, Vol. 16, Pt. 1, No. 217, p. 26.

CUSHMAN, J. A., AND HANZAWA, S. (1937), "Notes on Some of the Species Referred to *Vertebralina* and *Articulina*, and a New Genus *Nodobaculariella*," *Contrib. Cush. Lab. Foram. Res.*, Vol. 13, Pt. 2, No. 183, pp. 41–46.

CUSHMAN, J. A., AND HERRICK, STEPHEN M. (1945), "The Foraminifera of the Type Locality of the McBean Formation," *Contrib. Cushman Lab. Foram. Res.*, Vol. 21, Pt. 3, No. 268, pp. 55–73, Pls. 9–11. [New: *Planularia georgiana, Discorbis georgiana.*]

CUSHMAN, J. A., AND MCGLAMERY, WINNIE (1938), "Oligocene Foraminifera from Choctaw Bluff, Alabama," *U. S. Geol. Survey Prof. Paper 189-D*, pp. 101–19, Pls. 24–28. [New: *Globulina fimbriata, Buliminella choctawensis, Bolivina quadricosta, B. choctawensis, Discorbis choctawensis, Eponides choctawensis, E. alabamensis, Cancris sagra pauciloculata, Asterigerina choctawensis, A. alabamensis, Cibicides choctawensis.*]

——— (1939), New Species of Foraminifera from the Lower Oligocene of Alabama," *Contrib. Cushman Lab. Foram. Res.*, Vol. 15, Pt. 3, No. 209, pp. 45–49, Pl. 9. [New: *Dentalina pseudoinvolvens, Globulina alabamensis, Nonion decoratum, Nonionella oligocenica, Angulogerina hispidula, Virgulina alabamensis, Discorbis subpatelliformis.*

——— (1942), "Oligocene Foraminifera near Millry, Alabama," *U. S. Geol. Survey Prof. Paper 197-B*, pp. 65–84, Pls. 4–7.

CUSHMAN, J. A., AND OZAWA, Y. (1930), "A Monograph of the Foraminiferal Family Polymorphinidae, Recent and Fossil," *Proc. U. S. Nat. Mus.*, Vol. 77, Art. 6, pp. 1–185, Pls. 1–40, 2 text figs. [New from South Carolina: *Sigmomorphina vaughani.*]

CUSHMAN, J. A., AND PARKER, FRANCES L. (1935), "Some American Cretaceous Buliminas," *Contrib. Cushman Lab. Foram. Res.*, Vol. 11, Pt. 4, No. 164, pp. 96–101, Pl. 15. [New: *Bulimina prolixa*, from Tennessee.]

——— (1936a), "Notes on Some Cretaceous Species of *Buliminella* and *Neobulimina*," *Contrib. Cushman Lab. Foram. Res.*, Vol. 12, Pt. 1, No. 167, pp. 5–10, Pl. 2. [New from this region: *Buliminella vitrea, Neobulimina spinosa.*]

——— (1936b), "Some Species of *Robertina*," *Contrib. Cushman Lab. Foram. Res.*, Vol. 12, Pt. 4, No. 179, pp. 92–100, Pl. 16.

——— (1937), "Notes on some Oligocene Species of *Bulimina* and *Buliminella*," *Contrib. Cushman Lab. Foram. Res.*, Vol. 13, Pt. 1, No. 182, pp. 36–40, Pl. 4.

CUSHMAN, J. A., AND PONTON, G. M. (1931a), "A New *Virgulina* from the Miocene of Florida," *Contrib. Cushman Lab. Foram. Res.*, Vol. 7, Pt. 2, No. 104, pp. 32, 33, Pl. 4. [New: *V. miocenica.*]

——— (1931b), "A New *Plectofrondicularia* from Florida," *Contrib. Cushman Lab. Foram. Res.*, Vol. 7, Pt. 3, No. 109, pp. 60–62, Pl. 8. [New: *P. mansfieldi.*]

——— (1932a), "The Foraminifera of the Upper, Middle and Part of the Lower Miocene of Florida," *Florida Geol. Survey Bull. 9*, pp. 1–147, Pls. 1–17. [New: *Bigenerina floridana, Quinqueloculina chipolensis, Massilina quadrans, M. gunteri, M. incisa, M. spinata, M. spinata chipolensis, M. spinata glabrata, Articulina sagra miocenica, Triloculina quadrilateralis, longicostata, Flintina floridana, Pavonina miocenica, Bolivina plicatella mera, B. paula, Discorbis candeiana bullata, Asterigerina miocenica, Amphistegina floridana, A. chipolensis, Cassidulina chipolensis, Acervulina chipolensis.*]

——— (1932b), "Some Interesting New Foraminifera from the Miocene of Florida," *Contrib. Cushman Lab. Foram. Res.*, Vol. 8, Pt. 1, No. 116, pp. 1–4, Pl. 1. [New: *Annulocibicides projectus, Rectocibicides miocenicus, Cycloloculina miocenica, Virgulina gunteri curtata.*]

——— (1932c), "An Eocene Foraminiferal Fauna of Wilcox Age from Alabama," *Contrib. Cushman Lab. Foram. Res.*, Vol. 8, Pt. 3, No. 122, pp. 51–72, Pls. 7–9. [New: *Spiroplectammina wilcoxensis, Robulus wilcoxensis, Saracenaria wilcoxensis, Lingulina wilcoxensis, Triplasia wilcoxensis, Guttulina wilcoxensis, Pseudopolymorphina wilcoxensis, Sigmomorphina wilcoxensis, S. alabamensis, Nonion wilcoxensis, Nonionella wilcoxensis, N. alabamensis, Gumbelina wilcoxensis, Pseudouvigerina wilcoxensis, Robertina wilcoxensis, Virgulina wilcoxensis, Loxostomum wilcoxensis, Valvulineria wilcoxensis, Globorotalia wilcoxensis.*]

——— (1933), "A New Genus of the Foraminifera *Gunteria*, from the Middle Eocene of Florida," *Contrib. Cush. Lab. Foram. Res.*, Vol. 9, pt. 2, no. 129, pp. 25–30, pl. 3, f. 1–3. [New: *Gunteria floridana.*]

CUSHMAN, J. A., AND TODD, RUTH (1941), "Species of *Uvigerina* Occurring in the American Miocene," *Contrib. Cushman Lab. Foram. Res.*, Vol. 17, Pt. 2, No. 229, pp. 43–52, Pls. 12–14.

——— (1942a), "The Foraminifera of the Type Locality of the Naheola Formation," *Contrib. Cushman Lab. Foram. Res.*, Vol. 18, Pt. 2, No. 237, pp. 23–46, Pls. 5–8. [New: *Quinqueloculina plummerae, Dentalina delicatula naheolensis, Frondicularia naheolensis, Pseudouvigerina naheolensis, Lamarckina naheolensis, L. limbata.*]

——— (1942b), "The Genus *Cancris* and Its Species," *Contrib. Cushman Lab. Foram. Res.*, Vol. 18, Pt. 4, No. 240, pp. 72–94, Pls. 17–24. [New from Florida: *Cancris sagra communis.*]

——— (1943), "The Genus *Pullenia* and Its Species," *Contrib. Cushman Lab. Foram. Res.*, Vol. 19, Pt. 1, No. 241, pp. 1–23, Pls. 1–4.

——— (1944a), "The Genus *Spiroloculina* and Its Species," *Cushman Lab. Foram. Res. Spec. Pub. 11*, pp. 1–82, Pls. 1–9. [New: *Spiroloculina spissa, S. profunda.*]

——— (1944b), "Species of the Genera *Nodophthalmidium, Nodobaculariella*, and *Vertebralina*," *Contrib. Cushman Lab. Foram. Res.*, Vol. 20, Pt. 3, No. 259, pp. 64–77, Pls. 11, 12. [New from Florida: *Nodobaculariella multilocularis ornata.*]

——— (1945a), "A Foraminiferal Fauna from the Lisbon Formation of Alabama," *Contrib. Cushman Lab. Foram. Res.*, Vol. 21, Pt. 1, No. 266, pp. 11–21, Pls. 3, 4. [New from Claiborne Bluff: *Quinqueloculina mauricensis lisbonensis, Guttulina lisbonensis, Asterigerina lisbonensis, Cibicides howei.*]

——— (1945b), "Foraminifera of the Type Locality of the Moody's Marl Member of the Jackson Formation of Mississippi," *Contrib. Cush. Lab. Foram. Res.*, Vol. 21, p.t 4, no. 272, pp. 79–105, pls. 13–16. [New: *Quinqueloculina moodysensis, Q. tuberculata, Marginulina moodysensis, Nonionella jacksonensis compressa, Robertina moodysensis, Entosolenia howei, Bolivina moodysensis, Bitubulogenerina moodysensis, Cassidulina moodysensis, Cibicides plano-convexa.*]

——— (1946), "A Foraminiferal Fauna from the Byram Marl at Its Type Locality," *Contrib. Cushman Lab. Foram. Res.*, Vol. 22, Pt. 3, No. 280, pp. 76–102, Pls. 13–16. [New: *Quinqueloculina monroei, Q. crassa macerata, Q. mcglameryae, Triloculina byramensis, Pyrgo byramensis, P. monroei, Nodosaria praecatesbyi, Nonion alabamense, Nonion hantkeni byramensis, Bulimina byramensis, Reusella oligocenica, R. byramensis, Discorbis oligocenica, Lamarckina byramensis, Gyroidina byramensis, Asterigerina byramensis.*]

EDWARDS, R. A. (1944) "Ostracoda from the Duplin Marl (Upper Miocene) of North Carolina," *Jour. Paleon.*, Vol. 18, No. 6, pp. 505–28, Pls. 85–88. [32 new species of ostracodes, many of which occur in the *Cancellaria* zone of the Choctawhatchee of Florida.]

EHRENBERG, C. G. (1854), *Mikrogeologie. Das Wirken des unsichtbaren kleinen Lebens auf der Erde*, 2 vols., 40 pls. Leipzig. [Pl. 32 contains 48 figures labelled from "*Schreib-Kreide des Mississippi-Gebietes.*" Figured as new: *Miliola striata, M. laevis, Ovulina clava, Dentalina americana, Nodosaria tumescens, N. vulgaris, N. ampla, Vaginulina calcipara, V. cretae, V. subacuta, Planularia elongata, Textilaria striata, T. globulosa, T. inflata, T. stricta, Grammostomum americanum, G. phyllodes, G. invalidum, G. tessera, G. rhomboidale, Pleurites? americanus, Strophoconus spicula?, Sagrina longirostris, Proroporus obtusus, Spiroplecta americana, S. rosula, Dimorphina saxipara, Guttulina turrita, Frondicularia? trophoconus, Rotalia senaria, R. globulosa, protolepta, R. leptospira, R. calcipara, R. nonas?, Omphalophacus? tenellus, Planulina nebulosa, Cristellaria alta, Aspidospira saxipara, Rubulina? denaria, Rotalia reptas, Planulina mississippica, Phanerostomum asperum, Planulina oligosticta, Phanerostomum globulosum, P. quaternarium, Robulina ocellus, Planulina suboctonaria.*]

ELLIS, A. D., JR. (1939), "Significant Foraminifera from the Chickasawhay Beds of Wayne County, Mississippi," *Jour. Paleon.*, Vol. 13, No. 4, pp. 423, 424, Pl. 48. [New: *Nodosaria blanpiedi, Nonion struma, Elphidium rota, Cibicides hazzardi.*]

FINCH, JOHN (1824), "Geological Essay on the Tertiary Formations in America," *Amer. Jour. Sci.*, Vol. 7, pp. 31–43.

FISK, H. N. (1939), "Jackson Eocene from Borings at Greenville, Mississippi," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 23, No. 9, pp. 1393–1403, 3 text figs. [Lists of Foraminifera and Ostracoda—identifications by H. V. Howe.]

GABB, WILLIAM M., AND HORN, GEORGE H. (1862), "Monograph of the Fossil Polyzoa of the Secondary and Tertiary Formations of North America," *Jour. Acad. Nat. Sci. Philadelphia*, Ser. 2, Vol. 5, pp. 111–78, Pls. 19–21. [New from South Carolina: *Eschara texta, Reptescharella carolinensis;* from Alabama: *Eschara ovalis, Semieschara tubulata, Cellepora cycloris, C. inornata, Escharella micropora;* from Mississippi: *Reptocelleporaria glomerata.*]

GARRETT, J. B., JR. (1936), "Occurrence of *Nonionella cockfieldensis* at Claiborne, Alabama," *Jour. Paleon.*, Vol. 10, No. 8, pp. 785–786. [List.]

——— (1941), "New Middle Eocene Foraminifera from Southern Alabama and Mississippi," *Jour. Paleon.*, Vol. 15, pp. 153–56, Pl. 26. [New: *Hemicristellaria brantlyi, H. hatchetigbeensis*, and var. *harrisi, Discorbis washburni, Gyroidina lottensis, Eponides lowei, Cibicides hilgardi, C. williamsoni.*]

GEORGE, W. O., AND BAY, HARRY X. (1935), "Subsurface Data on Covington County, Mississippi," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 19, No. 8, pp. 1148-61. [Lists Foraminifera considered characteristic.]

GRAVELL, D. W., AND HANNA, M. A. (1935), "Larger Foraminifera from the Moody's Branch Marl, Jackson Eocene of Texas, Louisiana, and Mississippi," *Jour. Paleon.*, Vol. 9, No. 4, pp. 327–40, Pls. 29–32, 1 text fig. [New: *Camerina jacksonensis, C. moodysbranchensis.*]

——— (1938), "Subsurface Tertiary Zones of Correlation through Mississippi, Alabama, and Florida," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 22, No. 8, pp. 984–1013, Pls. 1–7, 5 text figs.

——— (1940), "New Larger Foraminifera from the Claiborne of Mississippi," *Jour. Paleon.*, Vol. 14, pp. 412–16, Pl. 57. [New: *Camerina barkeri, C. mississippiensis, Lepidocyclina (Lepidocyclina) claibornensis.*]

GREGORIO, ANTOINE DE (1890), "Monographie de la faune éocénique de l'Alabama," *Ann. Geol. Paleon.*, Vol. 7–8, pp. 1–316, Pls. 1–46. [Foraminifera. pp. 259–62, Pl. 46. New: *Mirfa subtetraedra, Cristellaria claibornensis, C. propesimplex, Orbitolites mantelli umbrellopsis, O. mantelli dispanopsis, O. mantelli optata, O. mantelli mustea.* Bryozoa described as new: *Crisia laeta, Myriozoum propepunctatum, M. fervens, Idmonea subdisticha, Entalophora amoena, Hornera mirifica, H. multiramosa, H. claibornensis, Eschara? spongiopsis, Escharella sifra, E. micropora asperulata, Vincularia? insolita, Lunulites (Disconfiustrellaria) bouei* vars. *concava, depressa, ellipsoides, truncata, almina, tiza, minutecellulata, Batapora convivialis, Celleporaria figula, Biflustra? supradubia, Membranipora simplex, M. contemplata, Lunulites (Dimiclausa) fenestrata.*]

HADLEY, WADE H., JR. (1935), "Seven New Species of Foraminifera from the Tertiary of the Gulf Coast," *Bull. Amer. Pal.*, Vol. 22, No. 74, pp. 1–10, Pl. 1. [New: *Bitubulogenerina chickasawhayica, Spiroloculina bidentata, Baggina xenoula, Pulvinulinella harrisi, Bifarina tombigbeensis, Massilina goniopleura, Gaudryina koimetercola.*]

HEILPRIN, A. (1882), "On the Occurrence of Nummulitic Deposits in Florida and the Association of Nummulites with a Freshwater Fauna," *Proc. Acad. Nat. Sci. Philadelphia*, pt. 2, 1882, pp. 189–93. [New: *Nummulites willcoxi.*]

——— (1884), "Notes on Some New Foraminifera from the Nummulitic Formation of Florida," *Jour. Acad. Nat. Sci. Philadelphia*, Ser. 2, Vol. 9, Pt. 1, pp. 321, 322, text figs. [New: *Nummulites floridensis.*]

——— (1887), "Explorations on the West Coast of Florida," *Trans. Wagner Inst.*, Vol. 1, 134 pp., 19 pls. [pp. 124–26 summarize the Foraminifera known from the Florida peninsula at that time.]

HOLMES, F. S. (1860), *Postpliocene Fossils of South Carolina.* xii+v+122 pp., 28 pls. Charleston. [Bryozoa described, but no new species.]

HOWE, H. V. (1928a), "An Observation on the Range of the Genus Hantkenina," *Jour. Paleon.*, Vol. 2, No. 1, pp. 13, 14, 2 text figs. [New: *H. inflata.*]

——— (1928b), "Additions to the List of Species Occurring in the Type Red Bluff Clay, Hiwannee, Mississippi," *Jour. Paleon.*, Vol. 2, No. 3, pp. 173–76. [Essentially a checklist.]

——— (1930a), "The Genus *Bolivinella* in the Oligocene of Mississippi," *Jour. Paleon.*, Vol. 4, No. 3, pp. 263–67, Pl. 21. [New: *Bolivinella subpectinata interrupta, B. compressa, B. vicksburgensis, B. rugosa.*]

——— (1930b), "Distinctive New Species of Foraminifera from the Oligocene of Mississippi," *Jour. Paleon.*, Vol. 4, No. 4, pp. 327–31, Pl. 27. [New: *Flabellina vicksburgensis, Gaudryina youngi, Mississippina monsouri, Loxostoma hiwanneense, Nonionella tatumi, Pleurostomella vicksburgensis, Tubulogenerina vicksburgensis.*]

——— (1934a), "The Ostracode Genus *Cytherelloidea* in the Gulf Coast Tertiary," *Jour. Paleon.*, Vol. 8, No. 1, pp. 29–34, Pl. 5. [New from this region: *Cytherelloidea tombigbeensis, C. tombigbeensis delicata, C. nanafaliensis, C. veatchiana, C. hiwanneensis, C. alabamensis, C. vicksburgensis, C. leonensis.*]

——— (1934b), "*Bairdia subdeltoidea* (Münster) in the American Tertiary," *Jour. Paleon.*, Vol. 8, No. 3, pp. 388, 389, 1 fig. [From St. Stephens, Ala.]

——— (1934c), "*Bitubulogenerina*, a Tertiary New Genus of Foraminifera," *Jour. Paleon.*, Vol. 8, No. 4, pp. 417–21, Pl. 51. [New: *B. vicksburgensis, B. hiwanneensis.*]

——— (1934d), "Preliminary Paleontologic Analysis of the Upper and Lower Chickasawhay Members of the Catahoula Formation," *Guidebook, Eleventh Annual Field Trip, Shreveport Geol. Soc.* pp. 22–28, Pl. 1, 2 checklists.

——— (1936), "Ostracoda of the Genus *Eucythere* from the Tertiary of Mississippi," *Jour. Paleon.*, Vol. 10, No. 2, pp. 143–45, 7 figs. [New from this region: *E. woodwardensis, E. chickasawhayensis, E. lowei.*]

——— (1942a), "Fauna of the Glendon Formation at Its Type Locality," *Jour. Paleon.*, Vol. 16, No. 2, pp. 264–91, 2 figs., checklist.

——— (1942b), "Neglected Gulf Coast Tertiary Microfossils," *Bull. Amer. Assoc. Petrol. Geo.*, Vol. 26, No. 7, pp. 1188–99, 25 figs.

——— (1943), "Use of Paleontology by the Oil Industry," *Jour. Sed. Petrology*, Vol. 13, No. 3, pp. 105–07.

HOWE, H. V., AND CHAMBERS, JACK (1935), "Louisiana Jackson Eocene Ostracoda," *Louisiana,*

Geol. Survey Bull. 5. 65 pp., 6 pls. [New from Eastern Gulf Region: *Paracypris franquesi, Cytheridea(?) garretti, Paracytheridea belhavenensis, Eocytheropteron spurgeonae, Buntonia shubutaensia, Cythereis grigsbyi, C. (?) israelskyi morsei, C. yazooensis, Loxoconcha jacksonensis, Brachycythere watervalleyensis, Xestoleberis sarsi.*]

HOWE, H. V., AND GARRETT, J. B., JR. (1934), "Louisiana Sabine Eocene Ostracoda," *Louisiana Geol. Survey Bull.* 4. 71 pp., 4 pls. [Checklist of Alabama Wilcox Ostracoda.]

HOWE, H. V., AND GRADUATE STUDENTS (1935), "Ostracoda of the *Arca*-Zone of the Choctawhatche Miocene of Florida," *Florida Geol. Survey Bull.* 13, pp. 1–47, 4 pls. [New: *Cytheridea chocawhatcheensis, C. floridana, Cytheromorpha warneri, C. warneri okaloosaensis, Cytherideis agricola, C. fabula, C. ulrichi, Cytheridella chambersi, Cythereis exanthemata marylandica, C. exanthemata gomillionensis, C. garretti, C. gunteri, Hemicythere conradi, H. dalli, H. dalli redbayensis, H. sellardsi, Basslerella miocenica, Cytheretta bassleri, C. karlana, C. karlana choctawhatcheensis, Cytherura wardensis, Paracytheridea chipolensis.*]

HOWE, H. V., AND LAW, JOHN (1936), "Louisiana Vicksburg Oligocene Ostracoda," *Louisiana Geol. Survey Bull.* 7, pp. 1–96, 6 pls. [New from Eastern Gulf Region: *Cytherella hannai, C. hiwanneensis, C. sylverinica, Cytherelloidea byramensis, C. byramensis conecuhensis, C. castleberryensis, C. murdercreekensis, C. vicksburgensis, Pontocypris (?) mississippiensis, Argilloecia hiwanneensis, Bairdia hazzardi, B. hiwanneensis, B. woodwardsensis, Cytheridea grigsbyi vicksburgensis* Stephenson (MS), *Paracytheridea byramensis, P. toleri, P. woodwardsensis, Cytheropteron galericulum, Monoceratina wallacei, M. youngi, Cythereis (Pterygocythereis?) alexanderi, C. blanpiedi, C. blandpiedi melvinensis, C. (?) kempi, C. vicksburgensis, C. (?) weaveri, C. woodwardsensis, Archicythereis stephensoni, A. sylverinica, Leguminocythereis cookei, L. verrucosus, Hemicythere kniffeni, Cytherideis byramensis, C. vicksburgensis, Cytherura byramensis, C. hilgardi, C. sylverinica, C. wailesi, Eucytherura murdercreekensis, Krithe hiwanneensis, K. vicksburgensis, Eucythere byramensis, Loxoconcha woodwardsensis, Cytheromorpha vicksburgensis, Xestoleberis vicksburgensis.*]

KLINE, VIRGINIA H. (1943), "Clay County Fossils. Midway Foraminifera and Ostracoda," *Mississippi Geol. Survey Bull.* 53, pp. 1–95, Pls. 1–8. [New Foraminifera: *Robulus pseudo-costatus inornatus, Saracenaria midwayensis, Bullopora chapmani hispida, B. laevis hispida, Gumbelina morsei, Entosclenia morsei, Chilostomella subtriangularis, Cibicides browni,* New Ostracoda: *Loxoconcha mississippiensis.*]

KOKEN, E. (1888), "Neue Untersuchungen an tertiaren Fischotolithen," *Zeitschrift. d. d. Geol. Gesell.*, Bd. XL, pp. 274–305, Pls. 17–19. [23 new species of Eocene and Oligocene otoliths described from Alabama and Mississippi.]

LEA, ISAAC (1833), *Contributions to Geology.* 227 pp., 6 pls. Philadelphia. [New Bryozoa from Alabama: *Lunulites bouei, L. duclosii, Orbitolites interstitia, O. discoidea.*]

LONSDALE, WILLIAM (1845), "Account of 26 species of Polyparia Obtained from the Eocene Tertiary Formations of North America," *Quar. Jour. Geol. Soc. London*, Vol. 1, pp. 509–33. [New from South Carolina: *Idmonea maxillaris, I. commiscens, Eschara petiolus, E. incumbens, E. linea, E. viminea, Hippothoa tuberculum.*]

MANSFIELD, W. C. (1939), "Note on Unreported Oligocene in Citrus County, Florida," *Jour. Washington Acad. Sci.*, Vol. 29, No. 2, pp. 45, 46, text fig.

MARTIN, JAMES L. (1939), "Claiborne Eocene Species of the Ostracode Genus *Cytheropteron*," *Jour. Paleon.*, Vol. 13, No. 2, pp. 176–82, Pl. 22. [New from this region: *Cytheropteron lisbonense.*]

MCGUIRT, JAMES (1934), "Bryozoa of the Upper and Lower Chickasawhay Members of the Catahoula Formation of Wayne County, Mississippi," *Guidebook Eleventh Annual Field Trip, Shreveport Geol. Soc.*, pp. 28–31, checklist.

——— (1941), "Louisiana Tertiary Bryozoa," *Louisiana Geol. Survey Bull.* 21. 177 pp., 31 pls. [Checklist of Bryozoa at type localities of Glendon and Marianna formations.]

MEYER, OTTO (1887a), "On Invertebrates from the Eocene of Mississippi and Alabama," *Proc. Acad. Nat. Sci. Philadelphia*, pp. 51–56, 1 pl. [List of Foraminifera by Woodward.]

——— (1887b), "Beitrag zur Kenntnis der Fauna des Alttertiärs von Mississippi und Alabama," *Senckenbergische Nat. Ges. Frankfurt, Ber.*, pp. 3–22, Pls. 1, 2, checklist of Foraminifera. [New Ostracoda: *Cythere mississippiensis, C. jacksonensis.*]

——— (1889), "Fish Otoliths of the Southern Old Tertiary," *Amer. Nat.*, Vol. 23, pp. 42–43.

MINCHER, ALBERT R. (1941), "The Fauna of the Pascagoula Formation," *Jour. Paleon.*, Vol. 15, No. 4, pp. 337–48, Pls. 46, 47. [New Ostracoda: *Anomocytheridea pascagoulaensis, A. ovata, Cytherura johnsoni, Microcythere johnsoni, Cytheromorpha pascagoulaensis.*]

MOBERG, M. W. (1928), "New Species of *Coskinolina* and *Dictyoconus?* from Florida," *Florida Geol. Survey 19th. Ann. Rept.*, pp. 166–75, Pls. 3–5. [New: *Dictyoconus? gunteri, Coskinolina cookei.*]

MONSOUR, EMIL (1937), "Micro-Paleontologic Analysis of Jackson Eocene of Eastern Mississippi," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 21, No. 1, pp. 80–86. [Faunal lists.]

MORNHINVEG, A. R. (1941), "The Foraminifera of Red Bluff," *Jour. Paleon.*, Vol. 15, No. 4, pp. 431–35. [Checklist.]

MORNHINVEG, A. R., AND GARRETT, J. B., JR. (1935), "Study of Vicksburg Group at Vicksburg,

Mississippi," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 19, No. 11, pp. 1645–67; 5 figs. [Range charts of Foraminifera.]

MORTON, S. G. (1833), "Supplement to the 'Synopsis of the Organic Remains of the Ferruginous-Sand Formation of the United States, Contained in Vols. 17 and 18 of This Journal," *Amer. Jour. Sci.*, Vol. 23, pp. 288–94, Pls. 5 and 8. [New: *Nummulites mantelli.*]

MOSSOM, STUART (1926), "A Review of the Structure and Stratigraphy of Florida with Special Reference to the Petroleum Possibilities," *Florida Geol. Survey 17th. Ann. Rept.*, pp. 169–268. [Numerous lists and well records of Foraminifera.]

MURRAY, GROVER, JR. (1938), "Claiborne Eocene Species of the Ostracode Genus *Loxoconcha*," *Jour. Paleon.*, Vol. 12, No. 6, pp. 586–95, Pl. 68. [New from this region: *Loxoconcha lisbonensis, L. mcbeanensis.*]

MURRAY, GROVER, JR., and HUSSEY, K. M. (1942), "Some Tertiary Ostracoda of the Genera *Alatacythere* and *Brachycythere*," *Jour. Paleon.*, Vol. 16, No. 2, pp. 164–82, Pls. 27, 28; 2 text figs. [Range chart: Wilcox-Vicksburg.]

PLUMMER, HELEN J. (1934), *Epistominoides* and *Coleites*, New Genera of Foraminifera," *Amer. Midland Nat.*, Vol. 15, pp. 601–08, Pl. 24, text figs. [New from this region: *Epistominoides midwayensis.*]

——— (1938), "*Adhaerentia*, a New Foraminiferal Genus," *Amer. Midland Nat.*, Vol. 19, No. 1, pp. 242–44, text figs. 1a–g. [New: *A. midwayensis.*]

SANDIDGE, J. R. (1932a), "Significant Foraminifera from the Ripley Formation of Alabama," Amer. Midland Nat., Vol. 13, No. 4, pp. 190–202, Pl. 19. [New: *Cibicides ripleyensis, Turrilina angulata, Ventilabrella plummerae.*]

——— (1932b), "Fossil Foraminifera from the Cretaceous Ripley Formation of Alabama," *Amer. Midland Nat.*, Vol. 13, No. 5, pp. 312–18, Pl. 29. [New: *Robulus alexanderi, Frondicularia berryi, Pulvinulinella ripleyensis, Anomalina harperi.*]

——— (1932c), "Additional Foraminifera from the Ripley Formation in Alabama," *Amer. Midland. Nat.*, Vol. 13, No. 6, pp. 333–77, Pls. 31–33. [New: *Gaudryina rudita.*]

——— (1932d), "Foraminifera from the Ripley Formation of Western Alabama," *Jour. Paleon.*, Vol. 6, No. 3, pp. 265–87, Pls. 41–44. [New: *Bigenerina ripleyensis, Heterostomella cuneata, Clavulina plummerae, Robulus aldrichi, Lenticulina jonesi, Dentalina pinnigera, Frondicularia trispiculata, Buliminella cushmani, Valvulineria ripleyensis, Gyroidina alabamensis, Globotruncana convexa.*]

SMITH, EUGENE A. (1881), "On the Geology of Florida," *Amer. Jour. Sci.*, Ser. 3, Vol. 21, pp. 292–309. [Florida Tertiary rather than alluvium on the basis of numerous occurrences of *Orbitolites.*]

SMITH, R. HENDEE (1941), "Micropaleontology and Stratigraphy of a Deep Well at Niceville, Okaloosa County, Florida," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 25, No. 2, pp. 263–86, 2 pls., 3 text figs. [New Ostracoda: *Hemicythere calhounensis, Cytheretta gardneri, C. dalli, C. spencerensis, C. calhouensis, C. okaloosaensis.*]

STEPHENSON, M. B. (1936), "Shell Structure of the Ostracode Genus *Cytheridea*," *Jour. Paleon.*, Vol. 10, No. 8, pp. 695–703, Pl. 94, text figs. [New from this region: *Cytheridea (Haplocytheridea) blandpiedi, C. (Clithrocytheridea) vicksburgensis.*]

——— (1937), "Middle Tertiary Ostracoda of the Genus *Cytheridea*," *Jour. Paleon.*, Vol. 11, No. 2, pp. 145–59, Pls. 26, 27, text figs. [New from this region: *Cytheridea (Haplocytheridea) chambersi, C.(H.) chambersi granulosa, C.(H.) hadleyi, C.(H.) hazzardi, C.(H.) hiwanneensis, C.(H.) watervalleyensis, C.(H.) watervalleyensis lawi, C. (Clithrocytheridea) grigsbyi chickasawhayana, C.(C.) grigsbyi jacksonensis, C.(C.) howei, C.(C.) shubutensis, C. (Leptocytheridea) fragillissima, C.(L.) mcguirti mississippiensis, C.(L.) wailesi, C.(L.) waynensis.*]

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RESERVOIR CHARACTERISTICS OF RATTLESNAKE OIL AND GAS FIELD, SAN JUAN COUNTY, NEW MEXICO[1]

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ABSTRACT

The Rattlesnake field is in the Navajo Indian Reservation about 7 miles southwest of Shiprock, in San Juan County, northwestern New Mexico. The field is near the northwest edge of the San Juan Basin.

The thickness of the sedimentary rocks penetrated by wells in the field is approximately 7,500 feet. The Mancos shale of Upper Cretaceous age is at the surface and the Ignacio quartzite of Cambrian age is the oldest formation reached. The Dakota sandstone of Upper Cretaceous age and the Hermosa formation of Pennsylvanian age contain oil pools at depths of approximately 800 and 6,700 feet, respectively. The Ouray-Leadville limestone of Mississippian and Devonian age contains a pool of helium-bearing natural gas at a depth of about 6,950 feet. This natural gas is exceptional in that it contains about 73 per cent nitrogen and 7.6 per cent helium.

The Rattlesnake structure is a northwest-southeast trending anticline, having a series of minor highs along its axis. The anticline has greater structural relief with depths, and the lower beds thin over the top of the structure. The dip of the older rocks is much greater on the west flank of the structure than on the east flank. The axial plane of the anticline is progressively farther west with depth, and the apex of the anticline is progressively farther south with depth.

Oil was discovered in the Dakota sand in February, 1924. To the end of 1945, a total of 4,321,753 barrels of oil had been produced from the Dakota. This oil may have a gravity as high as 76° API at the well, but quickly weathers to a gravity of about 60° to 64° API. In all, 115 wells have been drilled for production from the Dakota sandstone. Oil has been found in each of the three sandstone members of the formation.

A total of 489,563 barrels of oil was produced from the Hermosa formation by two wells. The discovery well was completed in June, 1929. The last oil was produced from the Hermosa formation in March, 1940. The gravity of the oil was about 40° API. The oil was found in the lower part of the formation, and data indicate that the production from the two wells was from two different porous zones.

Helium-bearing natural gas was first found in the Ouray-Leadville formation in June, 1942, but the first gas well was not completed until May, 1943. Both solution porosity and porosity in the interstices between coarse dolomite crystals have been found in this formation. Because of the high helium content of the gas, this gas pool is being held as a helium reserve by the Bureau of Mines, United States Department of the Interior.

INTRODUCTION

The Rattlesnake oil and gas field is in the Navajo Indian Reservation about 7 miles southwest of Shiprock, in San Juan County, northwestern New Mexico. An igneous intrusion, known as Shiprock, rises almost 2,000 feet above the general ground level, forming a very conspicuous landmark about 3 miles southwest of the field. The major part of the Rattlesnake structure is in the northeast part of T. 29 N., R. 19 W., and small parts are in T. 30 N., R. 19 W., and T. 29 W., R. 18 W.

The Dakota sandstone of Upper Cretaceous age and the Hermosa formation of Pennsylvanian age contain oil pools at depths of approximately 800 and 6,700 feet, respectively. The Ouray-Leadville limestone of Mississippian and Devonian age contains a pool of helium-bearing natural gas at a depth of about 6,950 feet.

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Previous reports[3,4,5,6,7] describe the early development of the oil pool in the Dakota sandstone and the production of oil from the Hermosa formation. The two wells formerly producing from the Hermosa formation have been abandoned, and production from the Dakota sandstone has declined greatly. However, the drilling of additional deep wells and the discovery of helium-bearing gas in the Ouray-Leadville limestone have greatly increased the information available concerning the Rattlesnake structure and should prove of interest in future development of the general area.

ACKNOWLEDGMENTS

The data used in preparing this report were gathered originally for use in obtaining and operating helium-gas properties in the Rattlesnake field from 1943 to 1945. A part of the data was obtained from the offices of the Federal Geological Survey at Farmington and Roswell, New Mexico, and from a geologic report and oral discussions by N. W. Bass of the Federal Geological Survey, who was cooperating in 1941 and 1942 with petroleum engineers of the Bureau of Mines in an investigation of helium resources. Work was done under the general supervision of R. A. Cattell, chief, Petroleum and Natural Gas Division, Bureau of Mines, Washington, D. C., and C. W. Seibel, supervising engineer, Bureau of Mines Helium Plants, Amarillo, Texas.

STRUCTURE

The Rattlesnake structure is near the northwest edge of the San Juan basin and is west of a prominent hogback formed by sandstones in the Mesaverde formation marking the edge of the basin. Formations older than the Mesaverde are exposed farther west. The Dakota sandstone, which provides the principal oil-producing reservoir in the Rattlesnake field, is exposed about 12 miles west of the field.

The Rattlesnake structure is a northwest-southeast-trending anticline, having a series of minor highs along its axis. The anticline has greater structural relief with depth, and the lower beds thin over the top of the structure. The dip of the older rocks is much greater on the west flank of the structure than on the east flank. The axial plane of the anticline is progressively farther west with depth, and the apex of the anticline is progressively farther south with depth.

[3] K. B. Nowels, "Development and Relation of Oil Accumulation to Structure in the Shiprock District of the Navajo Indian Reservation, New Mexico," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 12, No. 2 (February, 1929), p. 117.

[4] *Idem*, "Navajo Reservation Development," *Oil and Gas Jour.* (October 1, 1925).

[5] *Idem*, "Oil Production in Rattlesnake Field," *Oil and Gas Jour.* (June 7, 1928).

[6] Dean E. Winchester, "The Oil and Gas Resources of New Mexico," *New Mexico School of Mines, State Bureau of Mines and Mineral Resources, Bull. 9* (1933).

[7] Robert L. Bates, "The Oil and Gas Resources of New Mexico," *ibid., Bull. 18*.

STRATIGRAPHY

The thickness of the sedimentary rocks penetrated by wells in the Rattlesnake field is approximately 7,500 feet. The Mancos shale of Upper Cretaceous age is at the surface and the Ignacio quartzite of Cambrian age is the oldest formation reached. Descriptions of the formations follow.

Mancos shale.—All wells in the Rattlesnake field penetrate the basal 700 to 800 feet of the Mancos shale. The Mancos shale, in general, is a gray, slightly silty shale containing some calcite and bentonite. The Tocito sandstone member of the Mancos is exposed and forms ledges in several places in the field. It is a buff to gray, fine, irregularly grained, silty sandstone. Another sandstone member, occurring at a depth of approximately 350 feet, may be equivalent to the Ferron sandstone of Utah. This member is composed of beds of light gray, fine-grained, silty, calcareous sandstone that is in places interbedded with shale. A thin limestone bed near the base of the Mancos shale is correlated with the Greenhorn limestone.

Dakota sandstone.—The Dakota sandstone of Upper Cretaceous age occurs at depths of 700 to 800 feet in the Rattlesnake field. This formation is about 200 feet thick and consists principally of fine- to medium-grained gray sandstone with interbedded dark gray shale and a few coal beds. The sandstone is cross-bedded and lenticular and varies in texture from a silty sandstone to conglomerate. The formation may be separated, in general, into three sandstone beds, separated by shale, sandy shale, carbonaceous shale, and, in some places, thin coal beds. The lenticularity of the uppermost beds of the formation makes it difficult to pick the top of the Dakota sandstone in wells.

Most of the oil that has been produced and all the oil being produced at present in the Rattlesnake field have come from the Dakota sandstone.

Morrison formation.—The Morrison formation of Upper Jurassic age underlies the Dakota sandstone and occurs at a depth of about 980 feet. The formation is about 650 feet thick. The upper part of the formation consists principally of green to gray shales with interbedded white or light gray sandstones. The middle and lower parts of the formation consist principally of white to light gray sandstone interbedded with variegated shale. Most of the shale and sandstone has a green cast. The sandstones are fine to medium in texture. In some parts of the field, the lower part of the formation consists of gray to buff sandstone and shale.

San Rafael group.—The San Rafael group of Upper Jurassic age contains several formations, of which only the Entrada sandstone was identified in the Rattlesnake field. The depth to the top of the San Rafael group ranges from 1,450 to 1,650 feet. The upper part of the group consists of buff to pink medium-grained sandstone and some variegated shale. The middle part of the group consists of variegated, black, and maroon shale, some purplish shale, and some interbedded light buff sandstone.

The Entrada sandstone is probably represented by pink to reddish fine-

grained sandstone having well rounded grains that occur in the lowermost part of the group. In some wells the fine, red, shaly sandstone at the base of the San Rafael group might represent the Carmel formation of this group.

Wingate sandstone.—The Wingate sandstone, of Jurassic age, occurs in the Rattlesnake field at depths ranging from about 1,850 to 2,150 feet and is about 650 feet thick. The formation consists principally of red, fine- to very fine-grained sandstone. The sandstone is silty in many places, and in some parts of the field, dark gray, greenish, purplish, and variegated shale occurs interbedded with the sandstone. No show of oil or gas has been found in this formation, although the formation probably does contain some water.

Chinle formation.—The Chinle formation, of upper Triassic age, is reached at a depth of approximately 2,750 feet, underlying the Wingate sandstone. Its thickness is 1,120 to 1,200 feet.

The upper 650 feet of the formation consist of red, silty shale, a few interbedded, very fine-grained sandstones, some calcareous sandstones, and limestones. The remainder of the formation is made up of variegated shale, including red, green, gray, purple, and maroon, interbedded with some beds of sandstone that range from white to buff and from fine to medium grain. There is no record of any oil or gas shows in the Chinle formation in this area.

Shinarump conglomerate and Moenkopi formation.—The Shinarump conglomerate, of Triassic age, is about 200 feet thick and occurs at depths of approximately 3,950 feet to 4,000 feet in the Rattlesnake field. The Shinarump consists principally of coarse to conglomeratic, well rounded quartz grains that are buff to amber and white. A shale unit 50 to 60 feet thick, which underlies the Shinarump, is probably equivalent to the Moenkopi formation. It is composed of shale that varies from dark maroon or red to greenish gray. Minor oil shows have been found in the Shinarump conglomerate in southeastern Utah and southwestern Colorado, and it is producing oil in one well in the Rangeley field in northwestern Colorado. In the Rattlesnake field, however, this formation contains water that is under a high artesian head and caused considerable difficulty in drilling the Navajo well No. 1. The formation was not tested for water, but it is believed that it should be capable of producing a large amount with artesian flow. The water probably contains a large amount of dissolved minerals.

Cutler and Rico formations.—The top of the Cutler formation, of Permian age, is found at depths ranging from about 4,100 to 4,300 feet in the Rattlesnake field. The total thickness of the Cutler and Rico formations is about 1,425 to 1,600 feet. It is difficult to recognize the boundaries of the Rico formation; however, tentative boundaries have been made in some wells. Using this tentative information, it appears that the Cutler formation is about 700 to 750 feet thick and the Rico formation about 700 to 900 feet thick.

The upper part of the Cutler formation is made up of red to maroon silty to sandy shale and some interbedded sandstones; and there are many beds of calcareous silty shale in the lower part. This red, silty shale persists through the

entire formation, but in the lower part, the shale is more variegated, varying from maroon to red, purple, gray, and green.

The top of the Rico formation was tentatively placed at the uppermost limestone bed of a dominantly calcareous sequence of beds. The formation is made up principally of red and variegated calcareous shale and considerable gray to dark gray limestone. The limestones are dolomitic in part and seem to be interbedded with the shale. The base of the Rico formation was drawn at the base of the beds that are predominantly red. In the Rattlesnake field there are red shales lying immediately above the thick limestone section that is normally called Hermosa. According to Bass,[8] "The upper part of the supposed Hermosa sequence changes rapidly from dominantly gray limestone to mainly red shale containing minor amounts of limestone southwestward from the McElmo structure in southwestern Colorado to the Rattlesnake field and particularly south from the Rattlesnake field to the Tocito structure." Bass points out further that "If the lower boundary of the Rico formation is drawn at the base of the beds that are dominantly red, the formation described as Rico will be of widely different age" from place to place.

Hermosa formation.—The Hermosa formation, of Pennsylvanian age, lies at depths of approximately 5,700 to 5,800 feet in the Rattlesnake field. The thickness of the formation varies from about 1,050 feet to 1,200 feet.

The top of the formation is drawn on the basis of sample cuttings at the base of the predominantly red beds and at the top of the thick series of limestones of Pennsylvanian age. This thick section of limestones is predominantly light to dark gray and is finely crystalline to dense. Chert is not uncommon in the limestones, and there are a few interbedded gray shales. There are some thin, oölitic zones in the Hermosa, as well as some thin zones of porous gray limestones. The Paradox member of the Hermosa formation, widespread in southeastern Utah and southwestern Colorado, is not present in the Rattlesnake field.

The Hermosa formation has produced oil in two wells in the Rattlesnake field. A more detailed description of the formation will be given in the latter part of the report under the discussion of the reservoir characteristics in this formation.

Many shows of oil and gas have been found in the Hermosa formation in wells in northwestern New Mexico, southeastern Utah, and southwestern Colorado. Between 1908 and 1923 about 70 wells were drilled into the Rico and Hermosa formations in the San Juan oil fields, San Juan County, Utah, located in Tps. 41 and 42 S., Rs. 18 and 19 E., and a small quantity of oil was produced.

Molas formation.—The Molas formation, of Pennsylvanian age, occurs at depths ranging from 6,776 to 6,890 feet in the Rattlesnake field. Its thickness varies from 125 to 155 feet. The Molas formation overlies the Ouray formation, unconformably and its thickness varies erratically throughout the area.

[8] N. W. Bass, "Paleozoic Stratigraphy as Revealed by Deep Wells in Parts of Southwestern Colorado, Northwestern New Mexico, Northeastern Arizona, and Southeastern Utah," *U. S. Geol. Survey Prelim. Chart 7*, Oil and Gas Investig. Ser. (1944), p. 10.

The Molas formation consists principally of dark purple and red shale and some green, gray, and black variegated shale. The proportion of limestone in the formation varies considerably; some wells have a large amount of gray, dense limestone. In wells 100 and 24, the top of the formation was picked at the top of a local lens of light- to dark-gray shaly sandstone 25 to 50 feet thick.

Ouray limestone.—The Ouray limestone, as used in this report, according to Bass[9] is probably equivalent to the Ouray and Leadville limestones of Mississippian and Devonian age on their outcrop in the Las Animas River Valley in southwestern Colorado. It has not been possible to differentiate the two formations in the Rattlesnake field. Bass also states[10] "In general, its lithologic features are remarkably persistent throughout the region of these deep wells," including southeastern Utah, northwestern New Mexico, northeastern Arizona, and southwestern Colorado. The top of the Ouray limestone occurs at a depth of 6,920 feet in the Navajo well No. 1; 6,955 feet in the Rattlesnake well No. 1-G; 7,045 feet in Rattlesnake well No. 100; and 7,070 feet in Rattlesnake well No. 24. Only two of the wells in the Rattlesnake field have drilled entirely through the Ouray. In the Continental-Santa Fe Rattlesnake well No. 100, 215 feet of the Ouray were penetrated; and in the Continental-Santa Fe Rattlesnake well No. 24, 225 feet of the formation were penetrated. The Ouray limestone in the Tocito structure 16 miles south of the Rattlesnake field has a total thickness of 155 feet.

In the Rattlesnake field, the Ouray limestone consists of light gray to white coarsely crystalline limestone, medium-gray, dense limestone, resinous brown, coarsely crystalline dolomite, traces of chert, and some thin beds of oölites. The formation forms a reservoir for the helium-bearing natural gas in the Rattlesnake field and will be described in more detail under the discussion of reservoir characteristics of this formation.

Elbert formation.—The top of the Elbert formation, of Devonian age, was picked in the Rattlesnake field at the top of the uppermost bright green and dull purplish red shale beds occurring below the limestones and dolomites of the Ouray limestone. The depth to the top of the Elbert is 7,260 feet in the Continental-Santa Fe Rattlesnake well No. 100 and 7,295 feet in the Continental-Santa Fe Rattlesnake well No. 24. The Continental-Santa Fe Rattlesnake well No. 100 is the only well in the Rattlesnake field that penetrates the entire Elbert formation. The Elbert formation was found at a depth of 6,750 feet in the Tocito well on the Tocito structure south of the Rattlesnake field. The thickness of the formation is 145 feet in Continental-Santa Fe Rattlesnake well No. 100 and 168 feet in the Tocito well.

The Elbert formation is composed mainly of interbedded, dull, purplish red shale and silty shale, bright green shale, medium dark gray dolomite, and, in the lower part particularly, minor amounts of sandy shale and sandy dolomite and

[9] *Op. cit.*, p. 5.
[10] *Op. cit.*, p. 5.

thin lenses of hard, quartzitic sandstone. The percentage of dolomite is greatest in the lowest third of the formation. No showings of oil or gas have been found in the Elbert formation in this region.

Ignacio quartzite.—The Continental-Santa Fe Rattlesnake well No. 100 was drilled into a white quartzite from 7,405 to 7,407 feet. This quartzite is believed to be the Ignacio, although there are some quartzitic beds in the lower part of the Elbert formation. The Ignacio quartzite is Upper Cambrian in age and lies unconformably below the Elbert formation.

Igneous rocks.—Several igneous plugs and dikes occur in the area north, south, and west of the Rattlesnake field. None of the plugs or dikes occurs in the field proper; however, Shiprock, which is the most conspicuous of the plugs and rises to a height of approximately 2,000 feet, is about 3 miles southwest of the Rattlesnake field. The Navajo well No. 1 and well No. 1-G are $3\frac{1}{4}$ miles northeast of the Shiprock plug. Two large dikes radiate from Shiprock, one to the northwest and one to the south. A smaller dike extends from Shiprock in a northeasterly direction; and the Navajo No. 1 and 1-G wells lie approximately 2 miles north of this dike. As these intrusive igneous rocks cut the Mancos shale of Upper Cretaceous age, they are younger than the Upper Cretaceous formations that they cut.

FIELD DEVELOPMENT

SHALLOW WELLS

The first lease on the Rattlesnake structure was granted to S. C. Munoz on December 4, 1923. The Santa Fe Corporation was organized for development of the property and contracted with the Producers and Refiners Corporation to drill four wells to the Dakota sand on the structure. The terms of the lease also called for a deep test within a certain period. The first well was drilled with cable-tool equipment and completed as a small producer on February 27, 1924. All of the drilling materials, casing, camp equipment, and other supplies, had to be hauled from Gallup, New Mexico, over 100 miles of roads that were often virtually impassable.

Late in the fall of 1924, after oil was discovered in the Dakota sand in this field, the Continental Oil Company acquired an interest in the property and has operated it since that time.

The discovery well in the Dakota sandstone on the Rattlesnake structure was completed at 826 feet in the upper part of the Dakota for 10 barrels per day. The Dakota in this field contains three lenticular sandstone units; later, it was found that each of these zones was oil-bearing although, in many wells, there might be water in one or all of the three units. Drilling this additional thickness of sand gave the wells much larger potential. As an example, well No. 5 was first drilled to a depth of 758 feet in September 1924, and its initial production was 300 barrels of oil per day. After the lower sandstone of the Dakota was found to be oil-bearing in other wells, the No. 5 well was deepened to 839 feet and flowed at

the rate of 1,500 barrels per day. Many other wells were deepened later to increase production. Development continued until more than 100 wells had been drilled. Well No. 22 extended the productive area toward the south. A few additional wells were drilled as late as 1944; at that time, approximately 36 wells were still producing in the field. All of the wells were drilled with cable tools, and the production string of casing was set at the top of the Dakota sand. Nearly all of the Dakota wells flowed naturally at first, but later it was necessary to pump them.

Fresh oil produced from the Dakota sand may have a gravity as high as 76° API and is straw-colored. This oil is highly volatile and quickly weathers to a gravity of about 60 to 64° API. Upon weathering, the oil gives off vapors rich in butanes and propanes. It has been necessary to build a stabilization plant to remove these vapors so that the oil may be pumped through pipe lines. For many years, the excess butanes and propanes have been injected back into the field.

A sample of casinghead gas taken from the separator of well No. 21 at about 10 pounds pressure, in July, 1927, was analyzed by the Bureau of Mines helium plant at Fort Worth, Texas. The analysis follows.

	Percentage
Carbon dioxide	0.0
Oxygen	0.18
Nitrogen	1.14
Methane	9.83
Ethane	27.58
Propane	41.57
Butane plus	19.70
	100.0

The reservoir pressure in March, 1938, was from approximately 270–280 psi. Tests made at that time indicated a reservoir temperature of about 75°F. These tests were made in well No. 5, which was 826 feet deep.

Early in 1925 a 2-inch pipe line was laid approximately 13 miles to connect with the Mid-West Refining Company's 3-inch line from the Hogback field to Farmington, New Mexico. During the summer of 1926 a 4-inch pipe line, 96 miles long, was built to Gallup, New Mexico, where the oil was delivered to tank cars on a standard-gage railroad. Most of the oil delivered to this pipe line was taken to the Continental Refinery at Albuquerque, New Mexico. Field production declined until, in July, 1940, the transportation of oil through the 4-inch line was suspended, and later the line was removed. Oil now being produced from the Rattlesnake field is delivered by pipe line to the Continental Oil Company refinery at Farmington, New Mexico.

DEVELOPMENT OF DEEP FORMATIONS

The terms of the 1923 lease required the lessee to drill wells to a minimum depth of 3,000 feet, subject to a time limit and subject to possibilities of finding production above this depth. It was scheduled originally to make well No. 16 the

first deep test. However, this well was abandoned when it was proved dry in the Dakota sandstone. The first deep test was Continental-Santa Fe Rattlesnake No. 17 in the SE. ¼, NE. ¼ of sec. 2, T. 29 N., R. 19 W. This well was spudded in with cable tools in September, 1925; and, after considerable trouble, principally from water-bearing formations, was completed as an oil well on June 7, 1929, at a depth of 6,771 feet, in the Hermosa formation. This well had an initial open flow of 800 barrels of 40° API gravity oil. Four and three-quarter-inch casing was set at 6,497, however, there appeared to be a prolific water zone above the oil, and the well produced approximately 2 barrels of water to 1 barrel of oil during its producing life. In the latter part of 1931, production began to decline in this well, so a decision was made to clean out the well and later to deepen it. In the last few months of 1931 and the early part of 1932, the well was deepened to 6,985 feet in the Molas formation. The only oil and gas found in this well came from the Dakota formation of Upper Cretaceous age and from the Hermosa formation of Pennsylvanian age. Other porous formations that were drilled contained only water.

The second deep test was Continental-Rattlesnake No. 24, located 1,782 feet north of the south line and 145 feet east of the west line of Sec. 1, T. 29 N., R. 19 W. This well was commenced in August, 1930, and drilled to a total depth of 7,370 feet in the Elbert formation by June, 1932. It was completed as an oil well in September, 1932, with an initial production of 500 barrels per day with 5 per cent water from the Hermosa formation. The oil was produced from porous beds between the depths of 6,585 to 6,620 feet. The only oil or gas produced below the Dakota sandstone was in the Hermosa formation. This well was drilled through the Ouray formation, but there was no definite indication that gas occurred in the Ouray. After the well was drilled to its total depth, the water was being bailed from it when the well began to flow water and attempted to blow out. This action was stopped by the bridging of the hole. After bridging, the well was cleaned out to the oil-bearing formation. Those working at the well said that they believed most of the bridging material came from the Molas formation. It was suggested that the bridging might have been caused by a showing of gas in the Ouray limestone.

Wells Nos. 17 and 24 are the only two wells in the Rattlesnake field that produced commercial oil below the Dakota sandstone. All tests made on porous formations, with the exception of the Dakota sandstone and the oil-productive zone of the Hermosa formation, indicated that they contained only water. No additional oil was produced from well No. 17 after its deepening, and well No. 24 has been shut down since 1940.

After considerable seismograph work, Continental-Santa Fe Rattlesnake well No. 100 was located, 1,050 feet south of the north line and 1,608 feet west of the east line of the NE. ¼ of Sec. 2, T. 29 W., R. 19 W. Drilling was begun on this well on August 15, 1939, and completed on January 23, 1940, at the total depth of 7,407 feet in the Ignacio quartzite. This well was drilled entirely with

rotary tools. It was not a commercial producer of oil; however, some showings of oil and gas were found and were thoroughly tested without developing commercial production. Only water was obtained from the Ouray limestone.

All three of the above deep tests were permanently plugged and abandoned in the early part of 1943.

After additional geophysical work, the Continental Oil Company obtained from the Navajo Tribe an oil and gas lease covering 3,720 acres adjacent to, and lying south and west of, the 1923 lease. The fourth deep test in this field was started on this lease on April 2, 1942, in the center of the NE. $\frac{1}{4}$, NE. $\frac{1}{4}$, SW. $\frac{1}{4}$ of Sec. 13, T. 29 N., R. 19 W., which is about 2 miles southeast of the other three deep wells. This deep test is also a little more than $\frac{1}{2}$ mile south of the nearest well producing oil from the shallow Dakota sand. As this well was structurally low on the shallow formations, there was no indication of oil in the Dakota. The well is structurally high on the Ouray limestone. Practically no porosity was developed in the Hermosa formation. A few gas bubbles were detected in a foot of core from 6,409$\frac{1}{2}$ to 6,410$\frac{1}{2}$ feet.

After a surface string of casing was set at 280 feet, the well was drilled to a depth of 6,950 feet without any additional casing in the hole. The well developed a flow of fresh artesian water during drilling between the depths of 3,200 and 3,900 feet. Mud weighing 9.2 pounds per gallon or heavier was required to prevent the artesian water from flowing. A lost return section was encountered around 5,500 feet that would take mud heavier than 9.6 pounds per gallon. It was necessary to keep the mud weight between these two figures while drilling and coring below 5,500 feet. As no oil was found in the deep Pennsylvanian beds, it was decided to drill deeper. The well was drilled through the Pennsylvanian beds into the Ouray limestone. It was noticed that, while drilling from 6,948 to 6,950 feet, the formation softened considerably, and gas soon began to show in the mud. The 9.6-pound mud being used in the hole was not heavy enough to keep down the gas encountered at 6,948 feet. To keep the well from blowing out and possibly cratering, the control heads on the well were shut in. As soon as more mud could be obtained, the lower 1,200 feet of the hole were filled with 20-pound-per-gallon Baroid mud with the lighter mud above.

A gas sample was obtained for helium determination by John A. Frost of the Federal Geological Survey before the well was mudded off. This sample was analyzed in the laboratories at the Amarillo Helium Plant and found to contain more than 7 per cent helium, and the gas was incombustible. After finding this high helium content, the Bureau of Mines contracted with Continental Oil Company to test this gas formation. Seven-inch casing was run in the hole; but, because of a bridge at 5,760, the casing had to be set at that depth. Due to lost circulation zones below the casing, it was not possible to drill the hole deeper. To get a test of this gas zone, tubing was run to bottom and the well opened. Without getting the well entirely clean, tests indicated that the open-flow capacity of the well was about 2 million cubic feet per day. While attempting to clean

the well, the tubing plugged and bridges formed around the outside of the tubing so that it was impossible to pull it. Operations on the well were suspended from July 26, 1942, to March 31, 1943.

On resuming operations heavy oil was pumped into the formation, and the tubing string was washed over and removed from the well. Five and one-half-inch O. D. casing was set at 6,940 feet with 300 sacks of cement. The well was drilled to a total depth of 7,036 feet in the Ouray formation. Water was encountered at 7,024 feet in the top of a buff porous dolomite bed in the Ouray limestone. The well was plugged back to 7,004 feet in a section of dense white limestone and, after acidizing with 1,000 gallons of acid, was completed as a gas well on May 17, 1943. The open-flow capacity was 33,000,000 cubic feet per day. The shut-in wellhead pressure was 2,990-psi gage.

The fifth deep well drilled on the Rattlesnake structure is known as the Bureau of Mines-Rattlesnake well No. 1-G and is in the center of the SE. $\frac{1}{4}$, SE. $\frac{1}{4}$ of Sec. 13, T. 29 N., R. 19 W. This well was spudded-in on June 6, 1943. The Dakota sandstone was drilled from 830 to 980 feet. An intermediate string of casing was set at 4,352 feet to shut off the artesian water zones. The top of the Hermosa formation was found at a depth of 5,780 feet. No oil or gas shows were found in the Hermosa formation in this well, and there was no indication of any development of porosity. The production string of casing was set at 6,971 feet, and the well was completed in the Ouray limestone at the total depth of 7,049 feet. The well had an initial open flow of 17,300,000 cubic feet per day without acidization. The well was completed, August 26, 1943.

OIL AND GAS OCCURRENCES

The only occurrences of oil or gas in the Rattlesnake field have been in the Dakota sandstone, the Hermosa formation, and the Ouray limestone. All other porous zones have either been non-productive of oil and gas or productive of water only.

The Dakota sandstone contains three sandstone units separated by beds of shale. Each of these sandstone units is highly lenticular. The occurrence of oil and water in these three units is erratic, and it may be possible to have oil or water or both in all three. Oil and gas occurred in the Hermosa formation in thin porous zones, probably either oölitic zones or zones formed by solution porosity. Some of the porous zones in the Hermosa apparently contain water, which is also associated with the oil where it is found in the Hermosa. The Continental-Santa Fe well No. 17 produced water along with the oil, and this water probably came from a porous formation above the porous zone productive of oil. There has been no indication of oil in the Ouray limestone. The gas occurs in the Ouray in the upper solution porosity zone, as well as the two upper zones where the porosity is formed by the interstices between coarse crystals of dolomite. Water was found in the lower porous dolomite zone and probably is associated with the gas in the other porous parts of the formation.

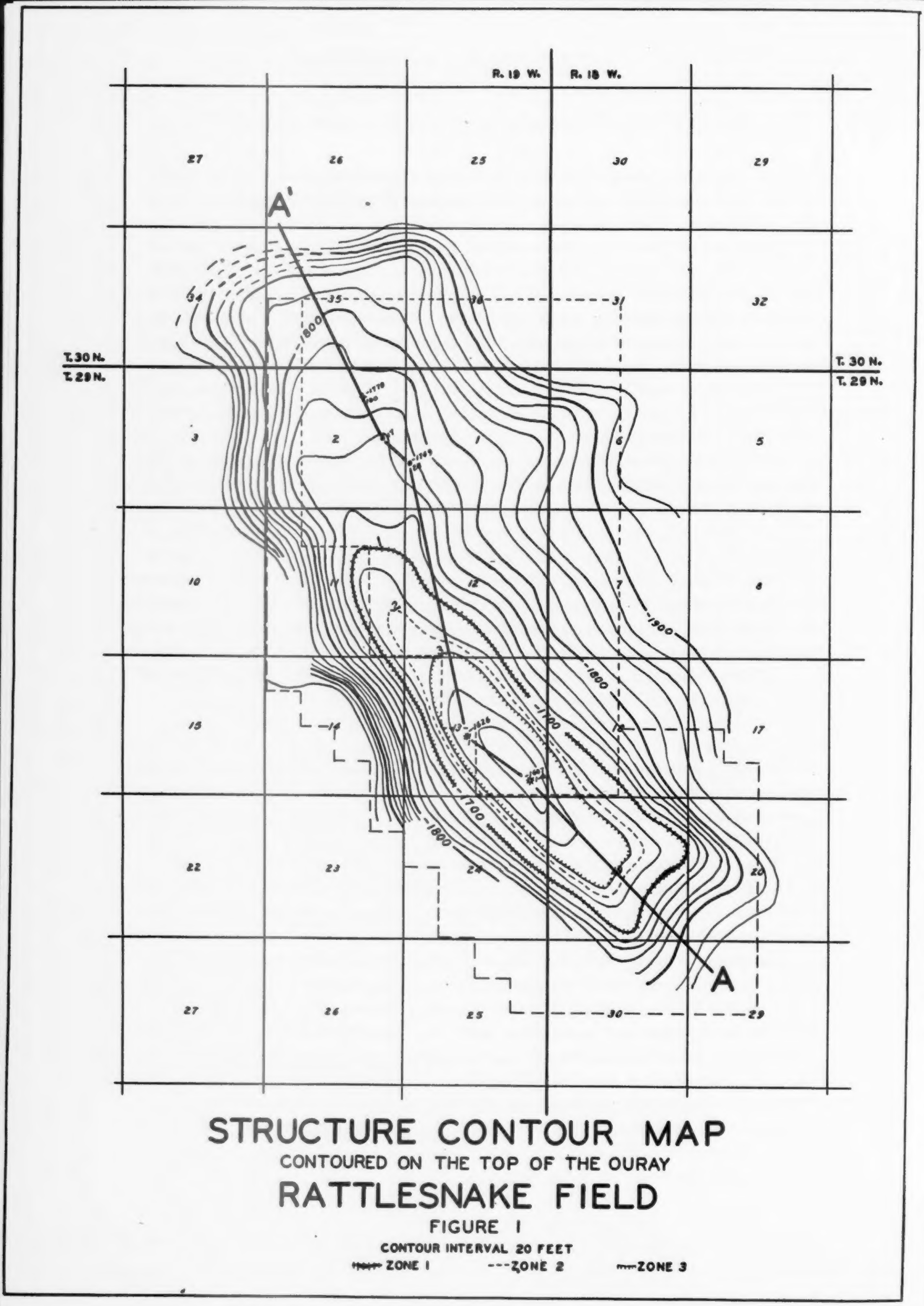


FIG. 1.—Structure contour map of top of Ouray limestone, Rattlesnake field.

Bass[11] has given the occurrence of oil and gas in other formations in fields throughout the region. In general, other fields in the area have had showings of oil or gas or were actually productive from the same pay formations as in the Rattlesnake field. A number of other formations not productive in the Rattlesnake field are productive elsewhere.

OURAY LIMESTONE

STRUCTURE

The structure on top of the Ouray limestone, as shown in Figure 1, is a northwest-southeast-trending anticline having a steep-dipping southwest flank. The structure on the top of this formation is interpreted from seismograph surveys and from cuttings from the four deep wells drilled into the formation.

The first seismograph survey was made in 1935 on the north part of the structure by the Continental Oil Company. The second survey was made by an independent company during April and May, 1940. The third survey was made by Continental Oil Company in September to November, 1941.

The apex of the structure on the top of the Ouray limestone is approximately 2½ miles south-southeast of the apex of the structure on top of the Dakota sandstone. The axis of the structure on the Ouray lies almost parallel with the axis on the Dakota but is offset southwest approximately ⅝ mile. The apex on the Ouray limestone lies almost directly beneath the apex on the top of the Hermosa formation. However, the structure on the Hermosa is flatter and does not dip northwest as steeply as the structure on the Ouray. The axis of the Ouray structure lies southwest of the axis of the Hermosa structure at distances varying from about ¼ to ⅝ mile.

DEVELOPMENT OF POROSITY

The Ouray limestone consists of limestone and dolomite. Four porous zones have been identified in this formation, one in the limestone and the other three in the dolomite. These porous zones and some of the structure of the formation are shown in cross section *AA′* of the Ouray limestone (Fig. 2).

Two types of porosity have been developed in the Ouray limestone. As mentioned previously, the Molas formation overlies the Ouray limestone unconformably. At the outcrop of the Ouray and Molas formations in the Rockwood quarry near Rockwood, Colorado, it is evident that the Ouray has suffered considerable solution and erosion. The lowermost few feet of the Molas formation are made up almost entirely of a coarse breccia of limestone fragments from the Ouray formation. The interstices of this breccia are filled with the red shale of the Molas formation. The upper parts of the Ouray have been badly weathered, and much of the material was dissolved. The solution cavities in the Ouray are filled with the red shale from the Molas formation above.

Cores cut from the wells in the Rattlesnake field indicate that the top of the

[11] *Op. cit.*

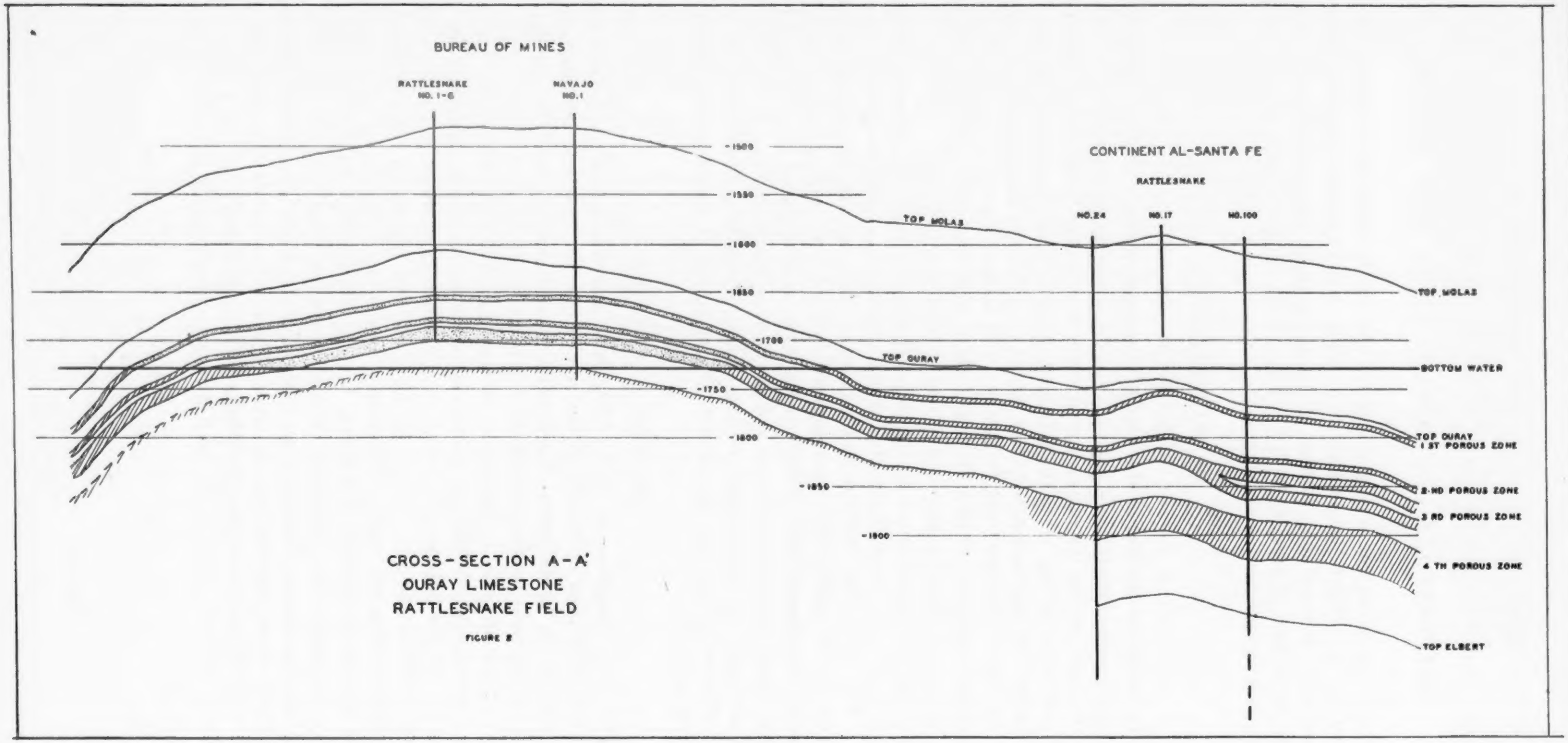


FIG. 2.—Cross section of Ouray formation, Rattlesnake field.

Ouray in this area also suffered extreme weathering, and the solution cavities are also filled with the red Molas shale. This solution porosity seems to take place to a depth of about 35 to 55 feet in the formation. Although the solution cavities in the upper part of the Ouray are filled with red shale, there is a porous zone about 5 feet in thickness in the lower part where red shale has not penetrated. This porous zone is productive of gas in the Navajo well No. 1 and Rattlesnake well No. 1-G. To summarize, the solution porosity in the limestone of the Ouray formation has been formed owing to the extreme weathering and solution of the upper part of the formation and is found only where the solution porosity is not filled with the red shale of the Molas formation above.

The other type porosity in the Ouray formation occurs in the interstices between the coarse crystals of buff to brown resinous dolomite. The dolomite zones begin to appear a few feet beneath the solution porosity zone. The upper dolomite zones are made up of gray to buff coarse crystalline dolomite with considerable porosity. The first porous dolomite zone is about 5 feet thick, followed by dense white to gray limestone and another dolomite zone averaging about 16 feet in thickness. Below the 16-foot dolomite zone in the two wells that have drilled through the entire formation are about 24 feet of white, dense limestone, followed again by about 40 to 50 feet of dark buff to brown resinous coarsely crystalline dolomite. The Rattlesnake No. 100 and No. 24 are the two wells that have drilled through the Ouray limestone.

In the Navajo No. 1 well and in the Rattlesnake 1-G well, gas occurs in the solution porosity zone and in the two upper crystalline dolomite zones. The Navajo well No. 1 was drilled into the lower dolomite zone and encountered water in the upper part. The Rattlesnake well No. 100 had water in all of the porous zones, and apparently the same zones in the Rattlesnake No. 24 were also filled with water. The Rattlesnake No. 24 well bridged while it was being bailed down, and it has been suggested that this bridging was caused by some gas in this well. However, there has been no definite proof that gas was encountered in well No. 24.

There have been shows of gas in this formation in the Tocito and Boundary Butte structures in this area. However, in the Biclahbito structure west of the Rattlesnake field, and in the Barker Creek dome northwest of the Rattlesnake field, the Ouray limestone contained water only. There is no record of any oil shows having been found in the Ouray in any part of northwestern New Mexico, northeastern Arizona, southeastern Utah, or southwestern Colorado.

As indicated in the cross section of the Ouray limestone (Fig. 2), bottom water was found in the Bureau of Mines-Navajo well No. 1 at 7,024 feet which is at an elevation of −1,730 feet. This bottom water appeared to be under considerable hydrostatic head and was produced along with the gas for a few hours before the well was plugged back. In the Navajo well, No. 1 this water occurred in the top of the fourth porous zone in the Ouray. This bottom-water level seems to be common to all the porous zones, as wells drilled into these porous zones below the bottom-water level have found only water.

An analysis of the bottom water was made by Karl E. Huber of the Federal Geological Survey laboratory in Casper, Wyo., and is given in Table I.

TABLE I

ANALYSIS OF WATER FROM OURAY LIMESTONE

	Parts Per Million	*Reacting Value*	*Value in Per Cent*
Sodium and potassium (calculated as sodium)	29,611	1,288.08	34.23
Calcium (Cal)	10,560	526.94	14.00
Magnesium (Mg)	808	66.42	1.77
Sulphate (SO_4)	705	14.66	0.39
Chloride (Cl)	66,000	1,861.20	49.46
Bicarbonate (HCO_3)	340	5.58	0.15

Total Solids Parts Per Million		*Properties of Reaction Per Cent*	
By evaporation	129,440	Primary salinity	68.46
After ignition	108,750	Secondary salinity	31.24
Calculated	107,854	Primary alkalinity	0.00
		Secondary alkalinity	0.30
		Chloride salinity	99.22
		Sulphate salinity	0.78

Even though these dolomite porous zones are separated by limestone, they probably form a common reservoir, at least so far as the gas accumulation is concerned. The vertical connections between the porous zones may be the result of joints and fractures formed at the time of origin of the anticlinal structure. Reference to the cross section indicates that these dolomite beds are remarkably uniform and persistent in the gas-bearing area of the field. The manner of formation of these dolomite zones is not known; however, they may have been formed either by precipitation of the dolomite crystals when the Ouray was deposited or by later dolomitization of the limestone.

The only cores taken in the limestone solution porosity zone (zone 1) were taken in the Bureau of Mines-Rattlesnake well No. 1-G. Core recovery was very poor in the porous section, and the cores taken are not representative of the porosity in that zone. No cores have been taken of the dolomite zones 2 and 3. Cores were taken in zone 4 in Continental-Santa Fe Rattlesnake well No. 100. Zone 4 is similar in porosity development to zones 2 and 3. Core recovery was better in zone 4 than in zone 1; however, only partial recovery was obtained in the fourth porous zone. Porosities and permeabilities on cores taken from zone 1 in the Bureau of Mines Rattlesnake well No. 1-G and from zone 4 in the Continental-Santa Fe Rattlesnake well No. 100 are given in Table II.

COMPOSITION OF GAS

The composition of the helium-bearing natural gas found in this formation is very unusual because of its high nitrogen content, as indicated by the following one-cut analysis.

	Percentage
Carbon dioxide	2.8
Oxygen	0.0
Methane	14.2
Ethane plus	2.8
Nitrogen	72.6
Helium	7.6
Total	100.0

The calculated gross heating value, in British thermal units, is 194 per cubic foot of dry gas at 60°F. and 30 inches pressure. The specific gravity of the gas as determined by a gravity balance is 0.897.

Liquid hydrocarbons amounting to approximately 0.2 gallon per thousand cubic feet of gas were produced with the helium-bearing natural gas during plant operations. These liquid hydrocarbons produced as part of the natural gas appear

TABLE II
CORE ANALYSIS FOR POROSITY AND PERMEABILITY*
Bureau of Mines Rattlesnake No. 1-G, Sec. 13, T. 29W., R. 19W., New Mexico

Laboratory No.	*Depth Feet*	*Porosity Percentage*	*Permeability Millidarcys*
1611	7,005–7,006	1.5	Less than 0.1
1612	7,006–7,007	2.0	0.1
1613	7,007–7,008	1.4	Less than 0.1
1614	7,011–7,012	2.7	0.1
1615	7,012	2.6	Less than 0.1
1616	7,015	1.7	Less than 0.1
Continental-Santa Fe Rattlesnake No. 100, Sec. 2, T. 29N., R. 19W. New Mexico			
1617	7,155–7,157	11.6	73.7
1618	7,160–7,162	8.0	2.0
1619	7,162–7,165	7.6	1.3
1620	7,175–7,178	12.9	65.3

* Analyses by Bureau of Mines Petroleum Experiment Station, Bartlesville, Oklahoma.

to be in the kerosene-distillate range and apparently occur in a gaseous form in the reservoir, as work with bottom-hole equipment has failed to detect any liquid hydrocarbons in the bottom of either the Rattlesnake well No. 1-G or Navajo well No. 1.

RESERVOIR PRESSURE AND TEMPERATURE

Bottom-hole temperatures and pressures were taken on the Bureau of Mines Navajo No. 1 and Rattlesnake 1-G by Espach, Morgan, and Fry, of the Bureau of Mines Petroleum and Oil Shale Experiment Station, Laramie, Wyoming, on October 4 and 5, 1944, after only a few million cubic feet of gas had been taken from the field. The bottom-hole pressure was found to be 3,605 pounds absolute, and the reservoir temperature was found to be 173°F. The pressure and temperature traverses are given in Table III.

TABLE III

BOTTOM-HOLE PRESSURE AND TEMPERATURE TRAVERSES
Bureau of Mines, Navajo No. 1, October 5, 1944

Depth Feet	*Gage Pressure, Psi (Amerada-Type Gage)*	*Temperature, °F. (Amerada-Type Gage)*
0	2,975	—
100	2,983	48
1,000	3,055	70
2,000	3,150	85
3,000	3,230	100
4,000	3,323	119
5,000	3,417	134
6,000	3,500	154
6,800	3,566	169
6,900	3,582	171
6,990	3,593	173
Bureau of Mines, Rattlesnake 1-G, October 4, 1944		
0	2,975	—
100	2,984	48
1,000	3,060	66
2,000	3,152	83
3,000	3,230	98
4,000	3,325	118
5,000	3,415	135
6,000	3,495	154
6,800	3,578	168
6,900	3,583	171
7,000	3,593	173

Traverses by Espach, Morgan, and Fry, Bureau of Mines Petroleum and Oil Shale Experiment Station, Laramie, Wyoming.

The temperatures were taken with an Amerada-type recording thermometer with a 200°F. maximum. The highest temperature recorded, 173°F., was found in the gas-producing zone. This temperature was recorded at an elevation of −1,665 feet in the Rattlesnake well No. 1-G and −1,710 feet in the Navajo well No. 1 a difference of 45 feet. As these readings are within the limits of accuracy of the recording temperature gage, this is as accurately as the temperature of the gas-producing zones can be determined. As a comparison, temperature surveys made during electrical logging at the time of the drilling of the wells gave temperatures near the gas pay of 126°F. in Rattlesnake 100, 146°F. in Rattlesnake 1-G, and 160°F. in Navajo No. 1. All of these temperatures were lower than the formation temperature, as they were taken with drilling mud in the hole and there was not an opportunity for equalization of temperatures between the mud and the formation.

Pressures were taken with an Amerada-type pressure gage with a maximum range of 5,000 psi. All pressures shown in Table III are gage pressures. The bottom-hole gage pressure of 3,593 psi was recorded opposite the gas "pays" in the two wells.

HERMOSA FORMATION

Five deep wells have been drilled through the Hermosa formation of Pennsylvanian age in the Rattlesnake field. Two of these wells obtained commercial production from the formation, and one other well obtained oil and gas showings. Well No. 17 produced 357,351 barrels of oil and well No. 24 132,212 barrels of oil, making a total of 489,563 barrels from the Hermosa formation. Data developed later in this discussion indicate that the commercial production from these two wells was from two entirely separate porous zones in the lower part of the Hermosa formation. In well No. 24, the oil was obtained from porous intervals between the depths of 6,585 to 6,620 feet. In well No. 17, the oil was produced from a 5-foot interval at about 6,720 feet.

OIL PRODUCTION

Well No. 17 produced oil continuously from April, 1929, through September, 1931, and produced a small volume of oil in April, 1932. This well produced considerable water along with the oil. It is believed that this water came from a porous zone between the seat of the producing string of casing and the top of the porous zone productive of oil. The oil production for this well, by months and by cumulative totals is given in Figure 3. The rate of production from this well reached the maximum shortly after the well was put on production, then declined during the remainder of its producing life.

Well No. 24 produced oil continuously from September 1932 until March, 1940. The well produced about 5 per cent water when it was completed but was never a prolific producer of water like well No. 17. The production of oil, by months and by cumulative totals, during the producing life of the well is given in Figure 4. The maximum rate of output was reached during the first month of the producing history, and the well never again reached as much as half of that rate. The production rate was erratic throughout the time of production and shows only a general downward trend. The well was not produced to depletion but was abandoned in April 1940 because of the loss of an electric pump in the hole.

STRUCTURE

The structure on top of the Hermosa formation is given in Figure 5. This structure is a northwest-southeast-trending anticline, with the north part of the structure trending almost north and south. The dip on the west flank of the structure is a little greater than that on the east flank. The Hermosa formation, as indicated by the structure map, has suffered much less deformation than the Ouray limestone and considerably more deformation than the Dakota sandstone. The axis of the anticline lies to the east of the axis on the Ouray and to the west of the axis on the Dakota. This axis does not parallel the axes on the other two formations previously mentioned but trends nearer the axis of the Dakota

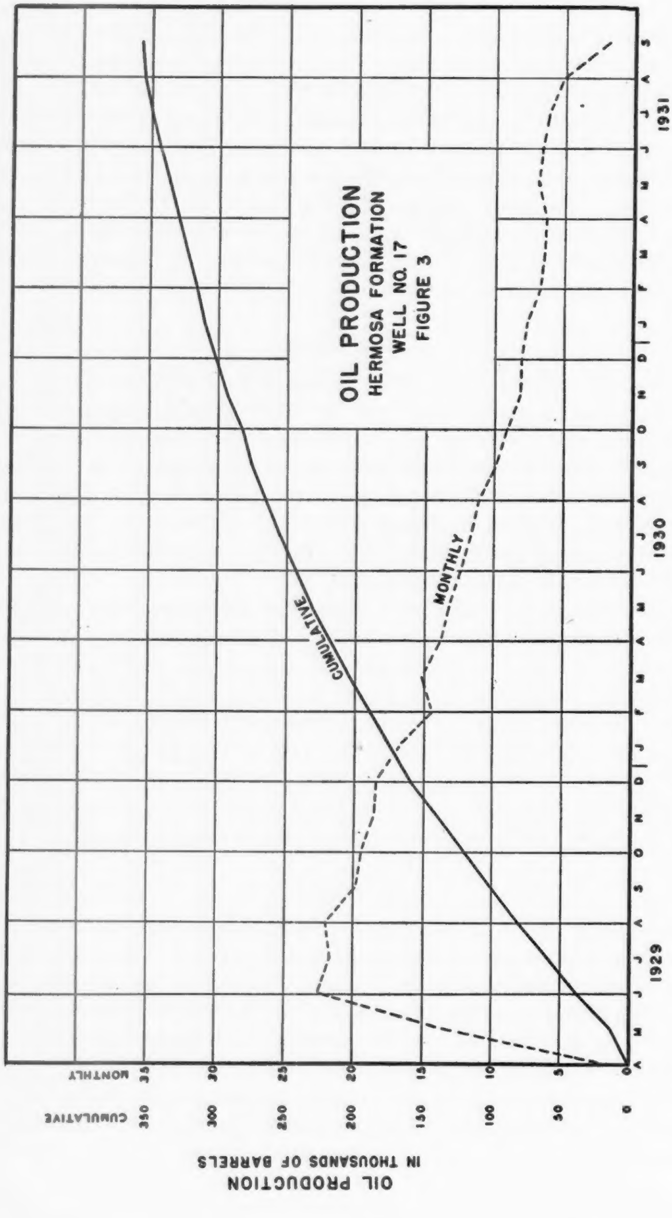


FIG. 3.—Oil production from Continental-Rattlesnake well No. 17.

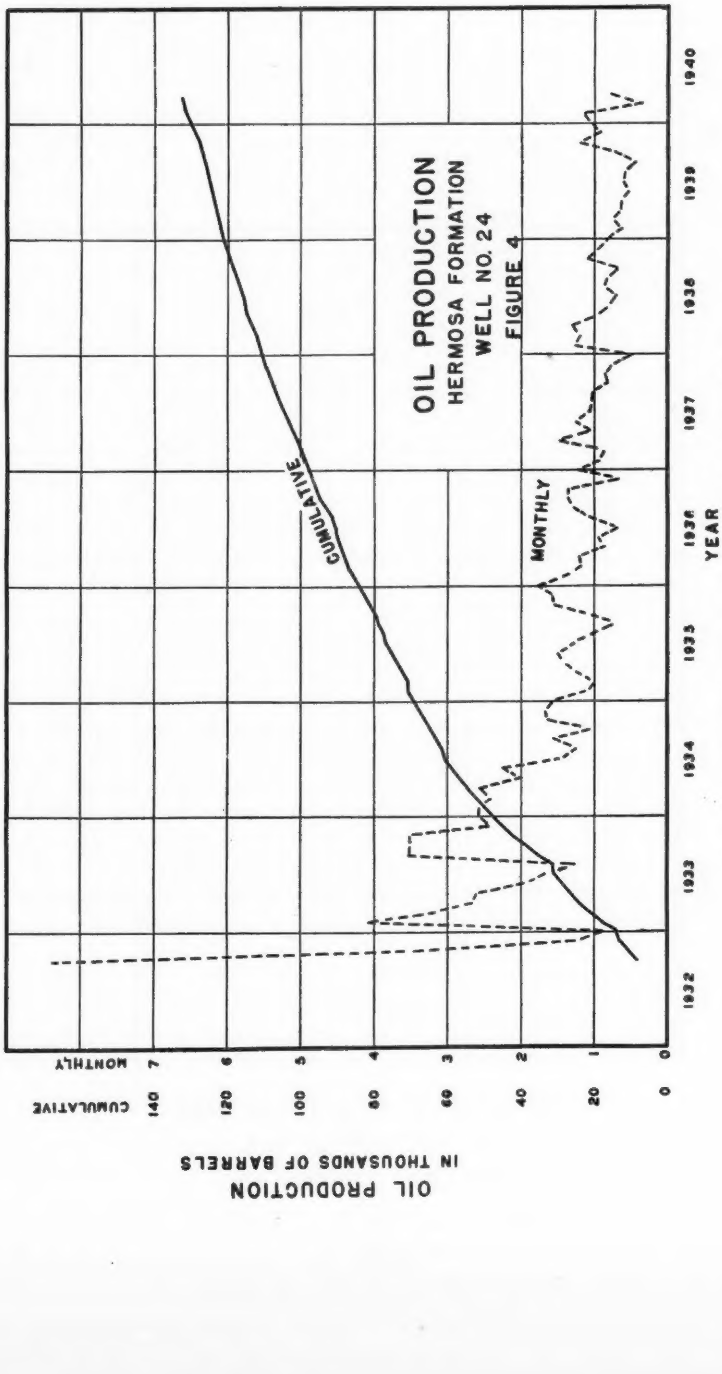
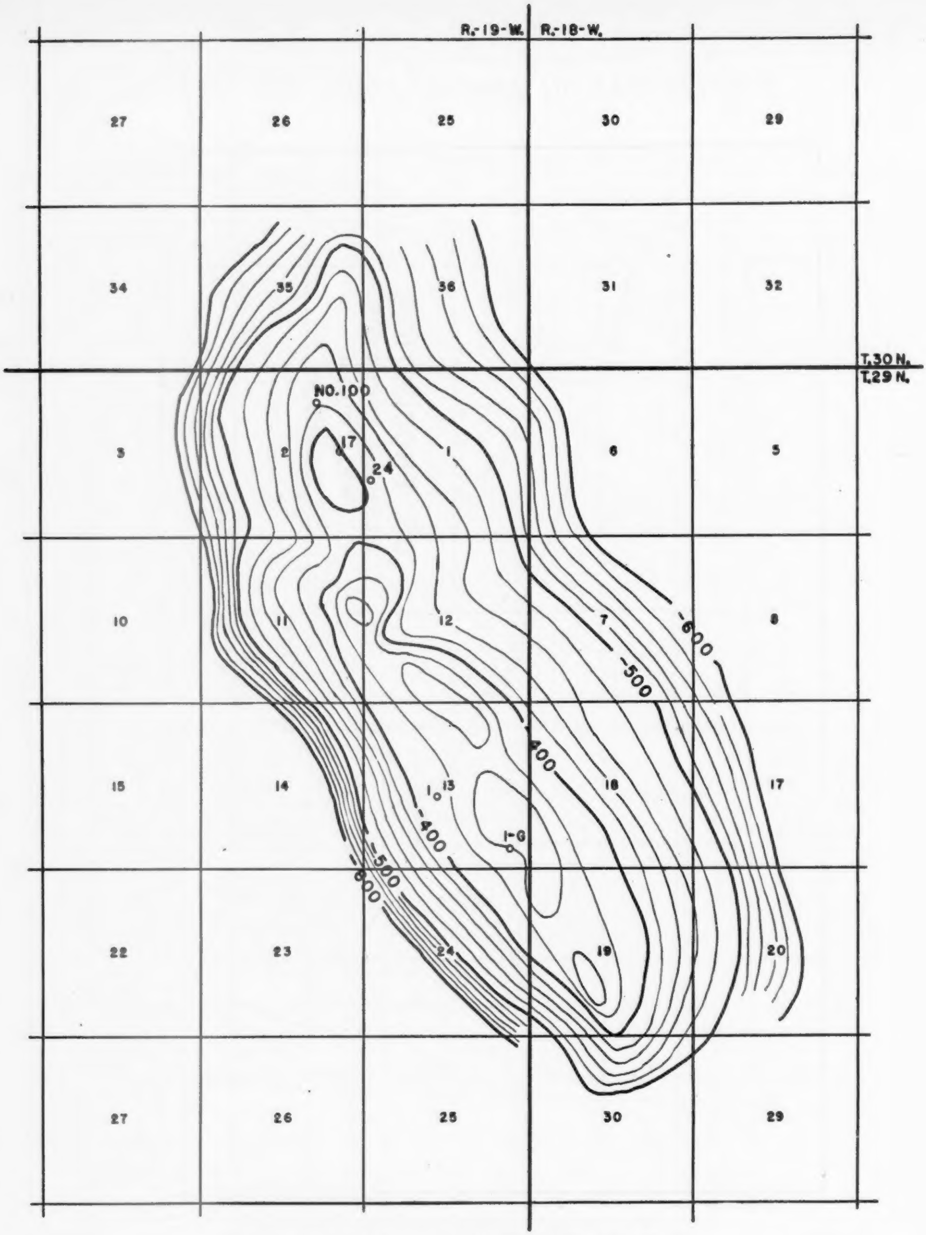


FIG. 4.—Oil production from Continental-Rattlesnake well No. 24.



STRUCTURE CONTOUR MAP
OF THE TOP OF THE
HERMOSA FORMATION
RATTLESNAKE FIELD
FIGURE 5
CONTOUR INTERVAL 20 FEET

Fig. 5.—Structure-contour map of top of Hermosa formation, Rattlesnake field.

structure in the northern part and nearer the axis of the Ouray structure in the southern part. The offset of the axis compared with the axes of the Dakota and Ouray structures gives further indication of the tilting of the structure downward to the northeast. The top of the structure is broader and flatter than the top of the structure on the Ouray limestone. The ends of the structure do not pitch as steeply as on the Ouray.

Oil produced from the Hermosa formation comes from the wells on the northern part of the structure, although they are structurally lower than the wells on the southern part of the structure. Very little porosity was developed in the Hermosa formation in the wells on the southern part of the structure, even though they were structurally higher. The lack of porosity in the higher wells may be due in part to thinning of the Hermosa formation over the top of the structure.

This structure map (Fig. 5) was developed through seismograph information and data from the five deep wells drilled on the structure. Although this map may be contoured on some bed immediately above the Hermosa, structural relief between the Continental-Santa Fe deep wells on the north end of the structure and the Bureau of Mines wells on the south end of the structure is the same as shown by correlation of the electric log on the individual wells, within the limits of accuracy of the seismograph survey. The structure based on this seismograph map shows a long anticlinal feature in approximately the same position as the structure on the Ouray, except that the axis is offset slightly to the northeast. The structure also has less relief on the Hermosa formation than on the Ouray. The lesser relief probably indicates that the structure was in progressive formation throughout Ouray and Hermosa time. This is substantiated further by the thinning of the beds in the Hermosa formation from the Continental-SantaFe well to the Bureau of Mines wells, which are structurally higher.

The structure as interpreted from this map shows five minor highs along the crest of the major structure, one located near the Bureau of Mines wells and another on the north end of the structure in the vicinity of Continental-Santa Fe wells Nos. 17 and 24. The minor high on the north end of the structure may have been of similar origin to the other highs but displaced downward during the tilt of the structure, making it at a lower elevation on the present structure.

CORRELATION

A cross section of the Hermosa formation in the Rattlesnake field, based on well records of the five deep wells that have drilled through the Hermosa formation, is given in Figure 6. The five deep wells are the Bureau of Mines Rattlesnake No. 1-G and Navajo No. 1, and Continental-Santa Fe Rattlesnake No. 17, No. 24, and No. 100. By sample examination, the top of the formation is drawn at the base of the predominantly redbed section and at the top of the thick series of limestones of Pennsylvanian age. The base of the formation is drawn on the top of the dark reddish to purple shale of the Molas formation. The Hermosa

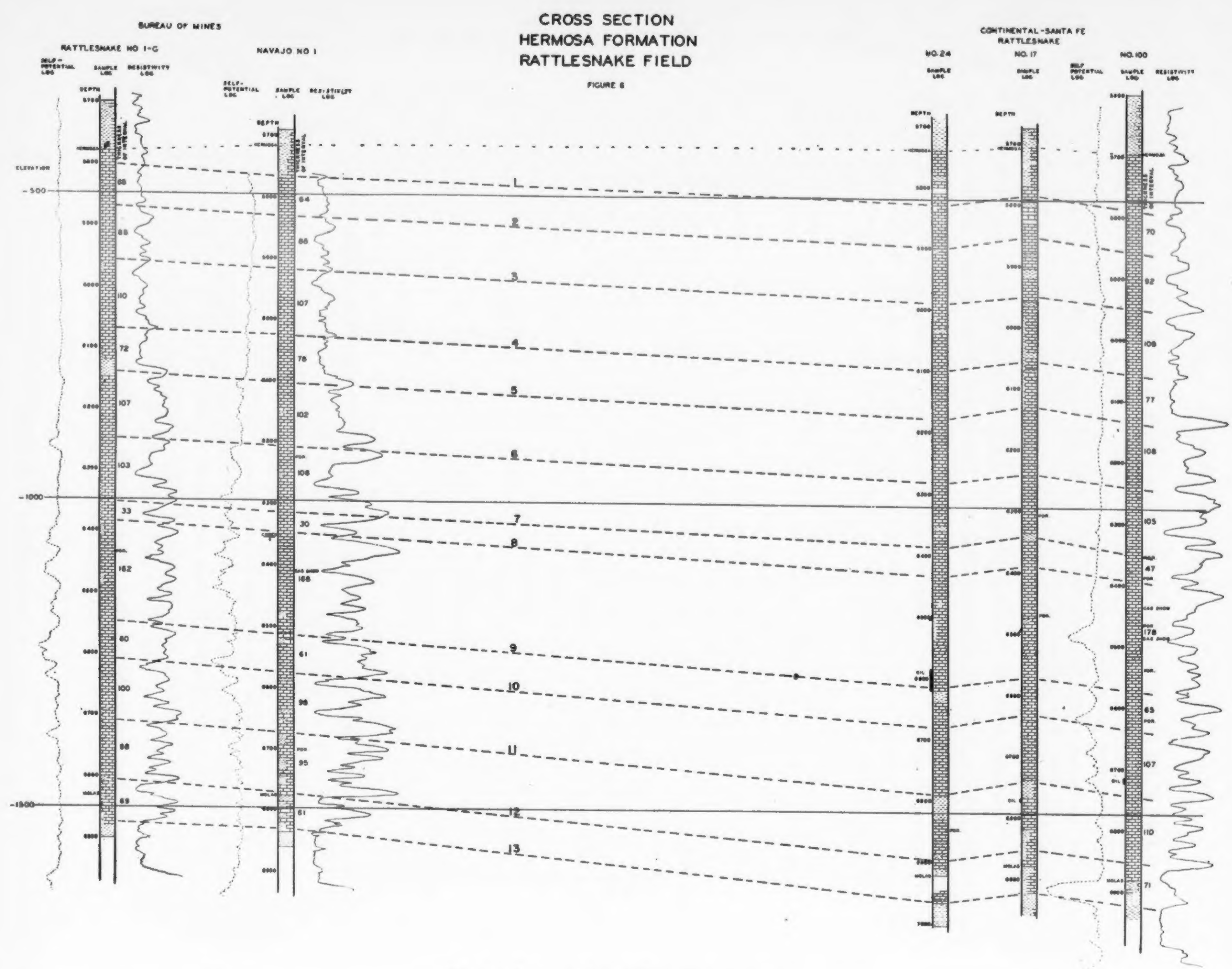


Fig. 6.—Cross section of Hermosa formation.

formation consists principally of massive limestones, predominantly light to dark gray in color and finely crystalline to dense in texture. There are numerous thin to thick-bedded gray shales throughout the formation and chert is not uncommon in the limestone. A few thin beds of dolomite have been found, as well as some oölitic zones.

Because of the lithologic change in the upper part of the Hermosa formation, the top, as determined from samples, does not represent the true structural position of this formation. The top of the formation, as shown by sample logs, is almost flat. This is shown by the light dashed line near the top of the cross section. The thickness of the formation in each well is as follows.

	Feet
Rattlesnake No. 100	1,193
Rattlesnake No. 17	1,179
Rattlesnake No. 24	1,183
Navajo No. 1	1,061
Rattlesnake No. 1-G	1,050

This thinning from the structurally lower north end of the anticline to the structurally higher south end of the anticline is due in part to the changing of the upper part of the formation from gray, dense limestone to redbeds as explained by Bass[12] and in part to the thinning of the individual limestone and shale beds, particularly in the lower part of the Hermosa formation.

In order to get the true structural position of the Hermosa formation, a correlation was made on the electric logs of wells No. 100, Navajo No. 1 and Rattlesnake No. 1-G. Starting in the characteristic Molas formation at the base of the Hermosa, these logs are easily correlated throughout the Hermosa formation Twelve correlation points were determined in the Hermosa and one in the Molas formation, giving a total of 12 intervals for comparison. The depths and elevations of each of the correlation points and the thickness of each interval are given in Table IV.

POROUS ZONES

The cross section (Fig. 6) of the Hermosa formation in the Rattlesnake field shows two porous zones that seem to persist across the field from the Continental-Santa Fe wells to the Bureau of Mines wells. The uppermost of these porous zones occurs in the interval between correlation points 8 and 9. This porous zone is identified in all of the wells except No. 24. Gas showings are indicated in well No. 100 and in Navajo well No. 1. The second porous zone is between correlation points 11 and 12 and is the porous zone in which oil was found in the Rattlesnake well No. 17. There may be other persistent porous zones, but owing to the difficulty of identifying porous zones in limestone formations, especially with rotary drilling, these zones may not have been identified in all of the wells. As the Hermosa formation was drilled in some of the wells and cored in others, the information regarding porous zones would not be consistent.

[12] *Op. cit.*, p. 10.

TABLE IV

Correlation Points on Electric Logs of Hermosa Formation, Rattlesnake Field

Depth, elevation, and thickness in feet

	No. 100			Navajo No. 1			Rattlesnake 1-G		
Points	*Depth*	*Elevation*	*Thickness*	*Depth*	*Elevation*	*Thickness*	*Depth*	*Elevation*	*Thickness*
Derrick Floor	0	5,275		0	5,294		0	5,348	
1	5,790	− 515		5,768	− 474		5,802	− 454	
			70			64			68
2	5,860	− 585		5,832	− 538		5,870	− 522	
			92			88			88
3	5,952	− 677		5,920	− 626		5,958	− 610	
			108			107			110
4	6,060	− 785		6,027	− 733		6,068	− 720	
			77			78			72
5	6,137	− 862		6,105	− 811		6,140	− 792	
			108			102			107
6	6,245	− 970		6,207	− 913		6,247	− 899	
			105			108			103
7	6,350	−1,075		6,315	−1,021		6,350	−1,002	
			47			30			33
8	6,397	−1,122		6,345	−1,051		6,383	−1,035	
			178			168			162
9	6,575	−1,300		6,513	−1,219		6,545	−1,197	
			65			61			60
10	6,640	−1,365		6,574	−1,280		6,605	−1,257	
			107			98			100
11	6,747	−1,472		6,672	−1,378		6,705	−1,357	
			110			95			98
12	6,857	−1,582		6,767	−1,473		6,803	−1,455	
			71			61			69
13	6,928	−1,653		6,828	−1,534		6,872	−1,524	
			1,138			1,060			1,070

Correlation point 1 was chosen below the top of the Hermosa formation as determined from sample logs. Point 13 was chosen in the upper part of the Molas formation. These correlation points and intervals are also shown on the cross section of this formation. From this table and the cross section, the beds which thinned from the Continental-Santa Fe wells to the Bureau of Mines wells may be determined. Almost all of the beds thinned from the Continental-Santa Fe wells to the Bureau of Mines wells, but the greater part of the thinning takes place in the beds in the lower half of the formation. The greatest thinning occurs in the small interval between correlation points 7 and 8, where 17 feet of section is lost out of the 47-foot section in well No. 100. The correlation point table and the cross section also indicate that the beds thicken slightly from the Navajo No. 1 well to the Rattlesnake No. 1-G.

The thinning of the beds from the Continental-Sante Fe wells to the Bureau of Mines well indicates that the structure was in process of formation during deposition of the Hermosa, the area around the Bureau of Mines wells rising in relation to the area around the Continental well. An approximate relation of the amount of thinning due to a change in lithology in the upper part of the formation compared with the thinning of individual beds in the formation may be obtained by comparing well No. 100 with the Navajo well No. 1. The Hermosa formation thins 132 feet from well No. 100 to the Navajo No. 1. The thinning of the individual beds is 68 feet between correlation points 1 and 12 in the two wells. These two points are both within the Hermosa formation and do not indicate the total thinning attributable to the individual beds. As the Rattlesnake well No. 1-G is now structurally higher than the Navajo well No. 1, the slight thickening of the beds from the Navajo well to the Rattlesnake well No. 1-G indicates that the structure has been tilted downward north or northeast. This tilt may be downward away from the Shiprock igneous plug, which lies southwest of the field, and may have occurred at the time of origin of the igneous plug.

Because of thinning of the beds in the lower part of the Hermosa formation from the structurally lower north end of the anticline to the structurally higher south end of the anticline, some of the porous zones may have been pinched out up structure. The Rattlesnake well No. 1-G shows only one porous interval between correlation points 8 and 9. The Hermosa formation in the Rattlesnake well 1-G was drilled with rotary tools and not cored, so it is possible that a number of small porous zones could have been drilled without being identified.

The Navajo well No. 1 was cored through the lower part of the Hermosa formation, and three porous zones were identified. The one lying between correlation points 8 and 9 showed porosity, with gas bubbles. The lower porous zone corresponds with the interval in which oil was found in well No. 17. It appears, however, by comparing data from Navajo well No. 1 with well No. 100, both of which were cored, that Navajo No. 1 well has fewer porous zones than well No. 100. All three Continental-Santa Fe wells on the north end of the structure either produced oil or had a very good showing of oil, whereas both of the Bureau of Mines wells had no indication of oil at all. Because of the pinching out of the beds over the higher part of the structure, stratigraphic traps may have formed along the flanks of the structure.

A rough approximation of the drainage area depleted by wells Nos. 17 and 24 can be determined by calculating the area that may have been drained by these two wells. For these calculations, an assumption was made that the porous zone in each well had a thickness of 5 feet and a porosity of 12 per cent, and that 60 per cent of the oil was recovered. Also, a connate-water content of 30 per cent was assumed. Another assumption was made that 1 barrel of oil at the surface would fill 1.40 barrels of space in the formation. Using these values with the estimated total production of the two wells, it is estimated that approximately 256 acres were drained. Considering that each well may have produced from a separate reservoir, this figure of 256 acres roughly equals the area of the minor high drilled by these two wells on the north end of the structure, indicating that these two wells may have drained all of the recoverable oil from this minor high.

DAKOTA SANDSTONE

The Dakota sandstone of Upper Cretaceous age occurs at depths of 700 to 800 feet in the Rattlesnake field and provides the principal oil reservoir of that field. The sandstone is cross-bedded and lenticular and varies in texture from a silty sandstone to conglomerate. Although the deposition was very irregular, the formation may be separated, in general, into three major sandstone beds. The total thickness of the formation is approximately 200 feet.

OIL PRODUCTION

The first commercially productive oil well in the Dakota sandstone was completed on February 27, 1924. To the end of 1945, a total of 4,321,753 barrels of oil had been produced from the Dakota in the Rattlesnake field. This oil may

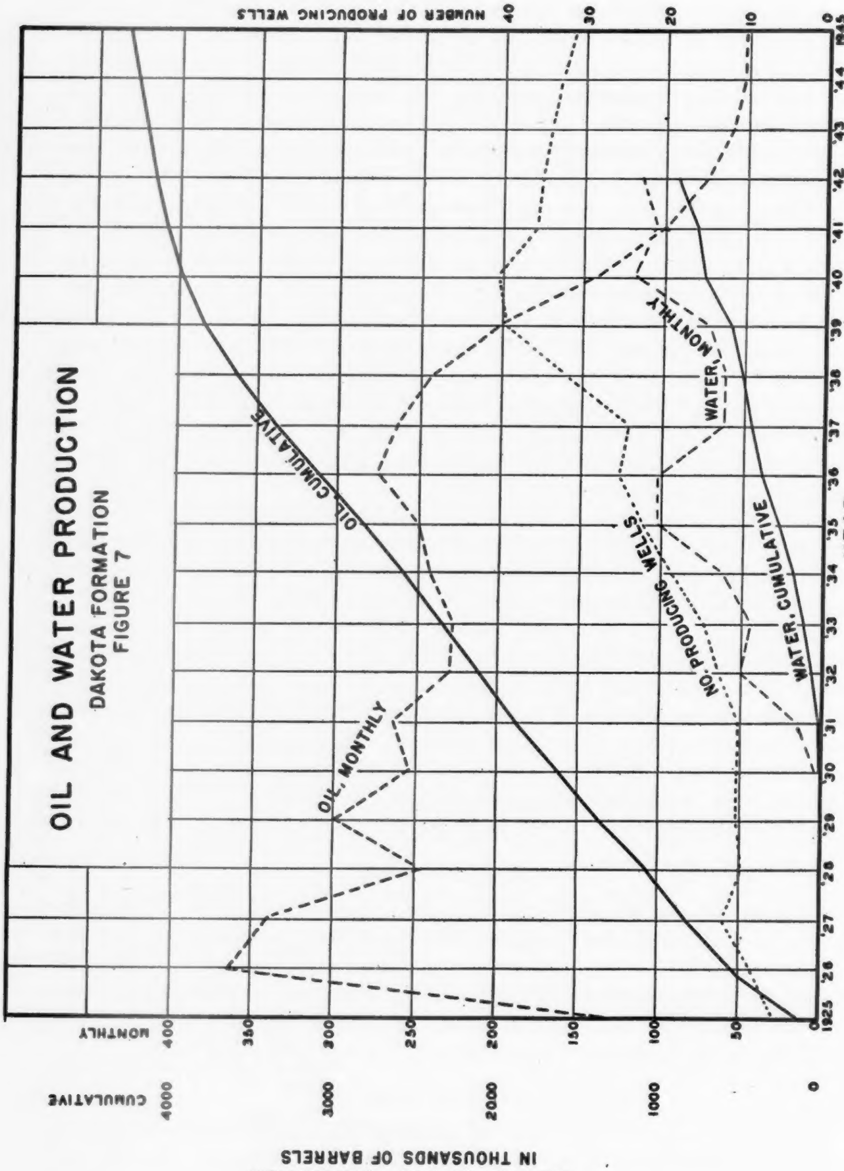


FIG. 7.—Oil and water production, Dakota sandstone.

have a gravity as high as 76° API and is straw-colored. The oil is highly volatile and quickly weathers to a gravity of about 60° to 64° API. Upon weathering, the oil gives off vapors rich in butanes and propanes. A sample of gas from the wells, taken in July, 1927, showed more than 41 per cent propane and approximately 20 per cent butane and heavier hydrocarbons.

All three sands are productive of oil, but it is exceptional to find more than one sand commercially productive at a given location. As the field lies on the Navajo Indian Reservation and is covered by one lease, the oil production from each individual well or from each sand has not been separated. A graphic record of the oil and water production is given in Figure 7. This figure shows cumulative oil production and the monthly average for each year. This figure also shows the water production by months and cumulative, from the beginning of water production through 1942. Although 120 wells have been drilled in this field, they have been drilled over a long period, and the maximum number producing at any one time was 44. Figure 7 also shows the average number of wells producing each year. The oil production reached a maximum of 367,253 barrels in 1926. The rate of production from the field has declined through the years, although a drilling campaign from 1931 through 1936 resulted in an increasing production from 1933 through 1936, the field declining more rapidly after that date. The maximum of 44 wells on production was reached in November of 1939.

Nine additional wells were drilled between November, 1943, and August, 1944, without increasing the field production materially. The field has now declined until it has almost reached the point of abandonment. The peak production of oil was reached during October, 1926, when 66,348 barrels of oil were produced. From May, 1926, to August, 1927, a period of 15 months, 624,686 barrels of oil were produced. There were only 12 wells in the field in October, 1926. The first water production began during October, 1930, when 10 wells were on production. The water production, by months, has varied somewhat as old wells were abandoned and new wells drilled, but the rate of water production in general has increased steadily through the years.

Due to the high volatility of the oil, it was necessary to build a stabilization plant to remove the vapors from the oil in order that it might be pumped through the pipe lines. The vapor from the oil is extremely rich in butanes and propanes, and these constituents of the vapor have been removed and sold commercially for a number of years. For many years the excess butanes and propanes and the lighter fractions of the vapor have been injected back into the field. In addition to the injection of the butanes, propanes, and lighter fractions into the Dakota formation, an effort was also made to repressure the field by air injection. A report on the injection program was included in a company report entitled "Report on the Rattlesnake Field, San Juan County, New Mexico," and is here quoted.

At different times, certain wells have been used as gas (high ends from stabilization plant) input wells with the idea of storage and repressuring. Well No. 6 was used as an

input well and was given up as such during August, 1941. Well No. 7 has been used as a gas input well and is still carried as a repressuring well on the field production report. Well No. 13 was completed on January 7, 1926, and produced oil from the first sand until June, 1927, when it was used as a gas input well to December, 1928. Well No. 22 was the only well which was used strictly as a repressuring well; the well was used as a repressure well from September 26 to November 18, 1940. During this time, 10,163,558 cubic feet of air were forced into the Dakota sand at a uniform pressure of 320 pounds per square inch. After repressuring for a few days, air introduced started to return by way of wells Nos. 97 and 99. These wells showed a constant increase in pressure with a decline in production of oil and an increase in water. Also, the water production from well No. 98 showed a marked increase with very little change in the oil produced.

Results of gas introduction in Wells Nos. 7 and 13 were noted in Wells Nos. 62, 63, and 85. Well No. 62 showed an initial production of 76 barrels of oil and 74,645 cubic feet of gas from the first sand, No. 63 showed an initial of 113 barrels of oil and 87,463 cubic feet of gas from the third sand, and No. 85, which was produced as a third sand well, showed 17 barrels of oil with 200,000 cubic feet of gas in the first sand on a two-hour test.

During the latter part of the life of the field, the marketing of butane obtained from the oil vapors has been a major factor in the field operations and has prevented earlier abandonment of the field. Well No. 111, which was drilled in December, 1943, produces butanes, propanes, and lighter fractions, which had been injected into the Dakota formation in earlier years. This well now provides a major source of butanes for marketing.

STRUCTURE

The Rattlesnake field is on the uppermost part of a large anticline. The axis of the structure trends almost north and south, deviating slightly northwest and southeast. As only the uppermost part of the structure is productive of oil, subsurface structure maps based on well data are limited to the area covered by the productive wells and near-by dry holes.

The structure as a whole can be defined best by the position of the Tocito sandstone member of the Mancos shale which occurs at the surface in most of the Rattlesnake field. The Rattlesnake structure was first defined by surface work based on this Tocito sandstone. The structure on top of the oil-bearing Dakota sandstone conforms, in general, with the surface structure, except for the deviations caused by the lenticular character of the upper part of the Dakota sandstone.

The first subsurface marker suitable for the determination of structure is the Greenhorn limestone member of the Mancos shale lying 60–70 feet above the Dakota sandstone. A comparison of the structure on top of the first Dakota sandstone (Fig. 8) with the structure of the top of the Greenhorn limestone (Fig. 9) reveals considerable difference in structural detail. Because oil is produced from each of the three sandstone members of the Dakota, structure contour maps were also drawn on top of the second Dakota sandstone (Fig. 10) and third Dakota sandstone (Fig. 11). The structure, as shown by Figures 10 and 11, also varies in comparison with the structure on top of the Greenhorn.

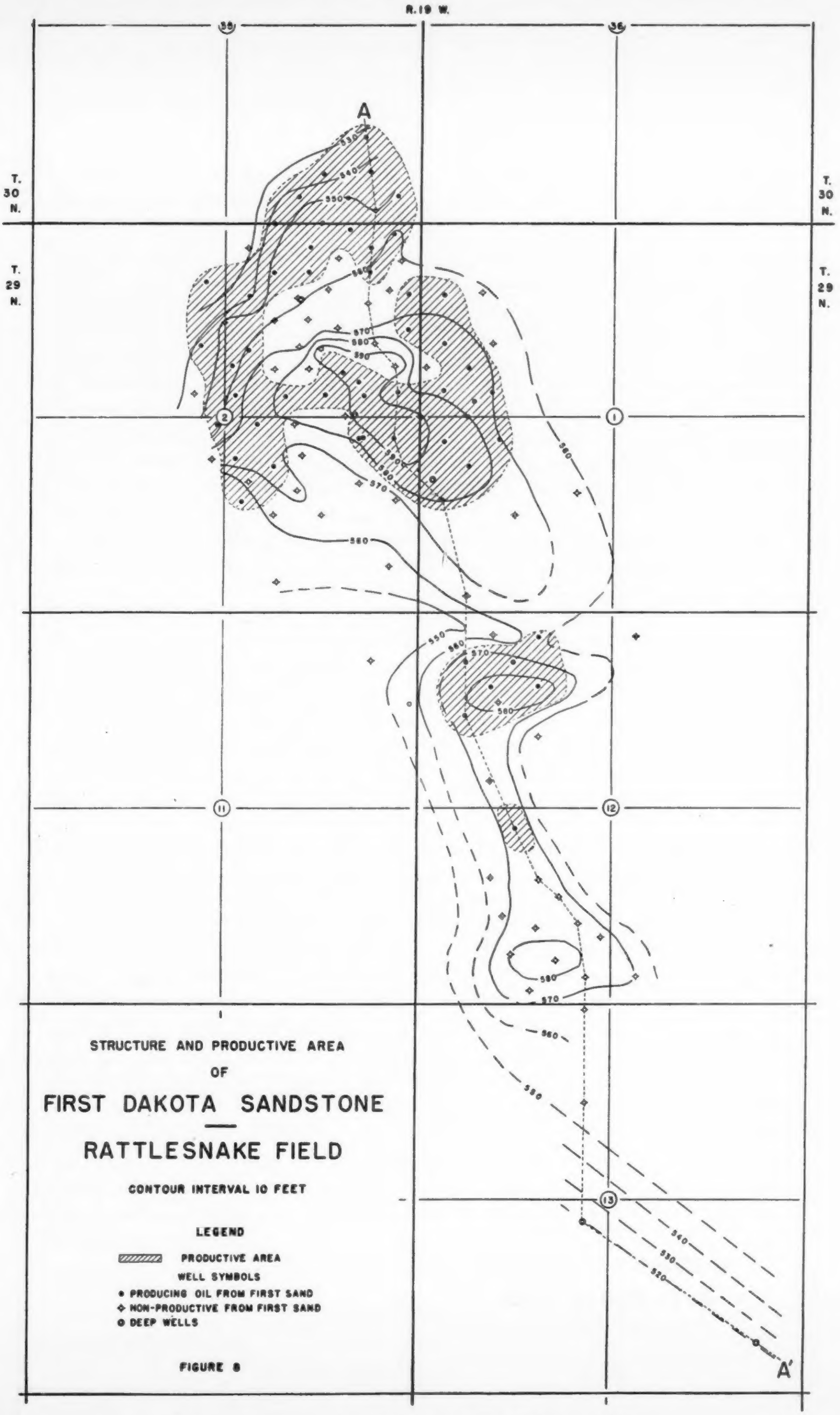


Fig. 8.—Structure and productive area, First Dakota sandstone.

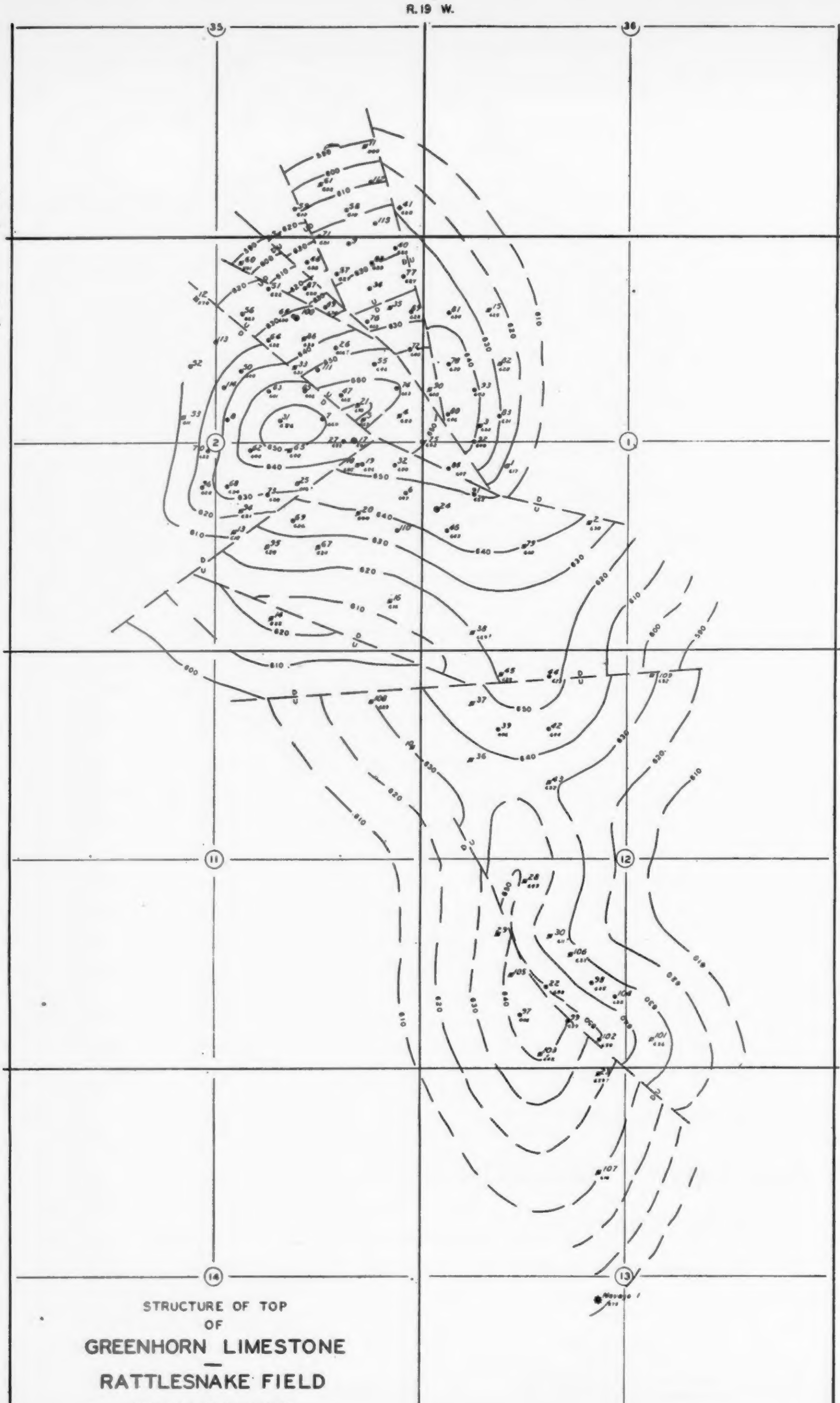


FIG. 9.—Structure of top of Greenhorn limestone.

The Dakota sandstone appears to be a shallow-water deposit having all of the variations in deposition attributable to that type of deposit, and its top is probably very irregular and varies somewhat in age over the structure. The structure contour map of the top of the Greenhorn limestone was made in an effort to describe more accurately the deformation of the Dakota sandstone by eliminating the factor of irregularity of deposition. As the Greenhorn is only from 5 to 10 feet in thickness, a more precise location of this bed in each of the wells can be made.

The location of the major axes and the range of contours are approximately the same on both the Greenhorn and Dakota maps. However, the entire field is cut by numerous faults as interpreted from the attitude of the top of the Greenhorn limestone. The major high in the northern part of the structure and the two minor highs in the southern half of the structure still exist but are changed considerably by the faulting.

The fault displacements range from a few feet to a maximum of about 30 feet. Some of the wedge-shaped faults increase in displacement away from the central part of the structure. The major fault is transverse, cutting through the central part of the field. One of the minor highs is on the upthrown side of this fault. The southernmost high area is cut by one large fault having a displacement ranging from about 10 feet to a little more than 20 feet. The major high area in the north part of the structure is cut by one large fault system consisting of one major fault with wedge-shaped faults radiating out from the major fault. All of the faulting is probably normal faulting and there is no evidence of thrust faults.

This faulting possibly extends through to the Dakota formation including all three of the sandstone members. Some of it may be due to slumping in the Mancos shale; however, it more probably is a result of the deformation that caused the Rattlesnake structure. This faulting probably influenced the accumulation and production of the oil from the Dakota sandstone.

First Dakota sandstone.—Figure 8 shows the structure of the top of the first or uppermost sandstone member of the Dakota sandstone. The structure consists of a long, narrow, elongate anticline with a major high in the north part and two minor highs in the southern half of the structure. The contours vary from an elevation of 4,520 feet to 4,590 feet, or a range of 70 feet; however, the actual closure in the productive area is much less than that. The shaded area of the map indicates the area productive of oil from the first or uppermost sandstone member of the Dakota. The irregularity of the contours may be due in part to the lenticular character of the sandstone and to minor faulting. The two minor highs on the south end of the structure and to some extent the major high on the north end suggest cross folding. In the two minor highs, the cross folding seems to be almost perpendicular to the axis of the major high. In the northernmost high area, however, the cross folding seems to be at an angle of about 30° to the axis of the major structure.

Second Dakota sandstone.—Figure 10 shows the structure on top of the second

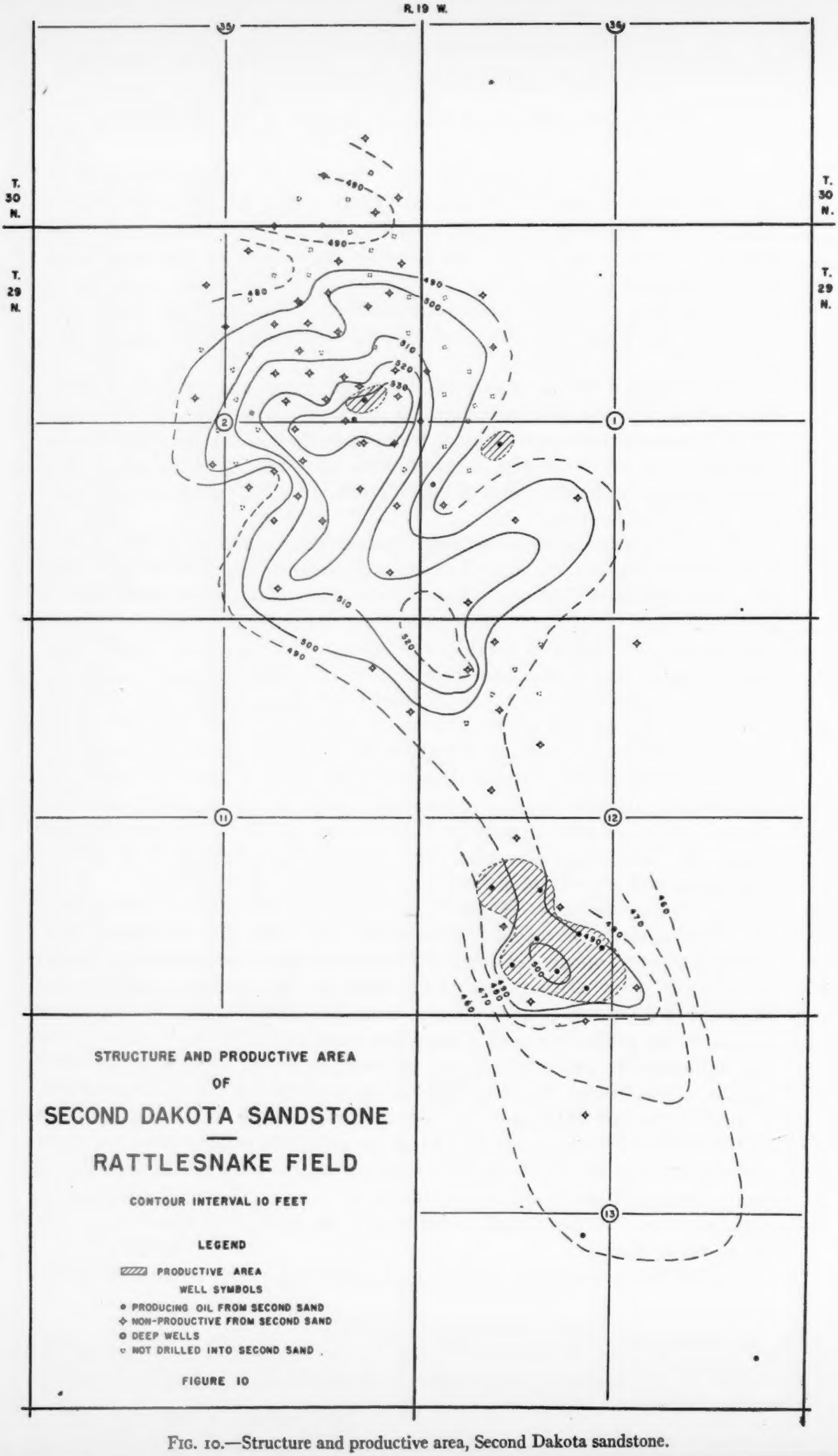


FIG. 10.—Structure and productive area, Second Dakota sandstone.

or middle sandstone member of the Dakota sandstone. On this map the middle high area is northwest of its position on the map of the top of the first Dakota sand. The southernmost high area is also displaced downward in elevation with respect to the major high area in the north part of the structure. The elevation of the top of this sandstone ranges from about 4,460 to 4,530 feet, giving a vertical range of approximately 70 feet, which is about the same as in the two previously discussed contour maps. The irregularity of the contours probably is due to the lenticular character of the sandstone and faulting. The relative lower elevation of the southernmost high undoubtedly must be due to thickening or thinning of the sandstone beds. The shaded area on the map is the area productive of oil from the second sandstone member.

Third Dakota sandstone.—Figure 11 shows the deformation on top of the third or lowermost sandstone member of the Dakota sandstone. The structure on the top of this bed is more regular than the structures shown on any of the other three members previously described. The southernmost high area is greatly elongate southeast, principally because of thinning of the second sandstone member, with a consequent rise of the top of the third member toward the two deep wells drilled on the southern part of the structure. The structure is flatter, and the total contour interval is only 50 feet compared to 70 feet in the other maps. The elevation of this sandstone ranges from 4,390 feet to 4,440 feet. The shaded part of the map indicates the area productive of oil from the third Dakota sandstone. Another unusual feature of the structure, as indicated by this map, is the southernmost high area having the same elevation as the major high area in the northern part of the structure.

OIL ACCUMULATION

Location.—The accumulation of oil is erratic in each of the three sandstone members of the Dakota when only structural conditions are considered. When the Rattlesnake structure is considered as a whole, the oil has accumulated only in the very highest structural part. The shading in Figure 8 shows the area of accumulation of oil in the first Dakota sand. Considering the structure on the top of the first Dakota sand, the oil has accumulated in the major high structural area in the north part of the field, in the central minor high, and at an isolated location between the two minor highs in the southern half of the field. In the northern part of the field, the accumulation has taken place across the highest parts of the structure and along the north and west sides of the structure, leaving a barren area on the north slope of the highest part of the structure. The central area is productive at the highest elevation. There is an isolated accumulation of oil in the first sand in the saddle between the middle and southern high areas.

The area of oil accumulation in the second or middle Dakota sandstone is shown by the shaded area in Figure 10. The productive area in the second sand is about one-fifth of that in the first sand and about one-third as much as in the third sand. The highest part of the structure, in the northern part of the field, has

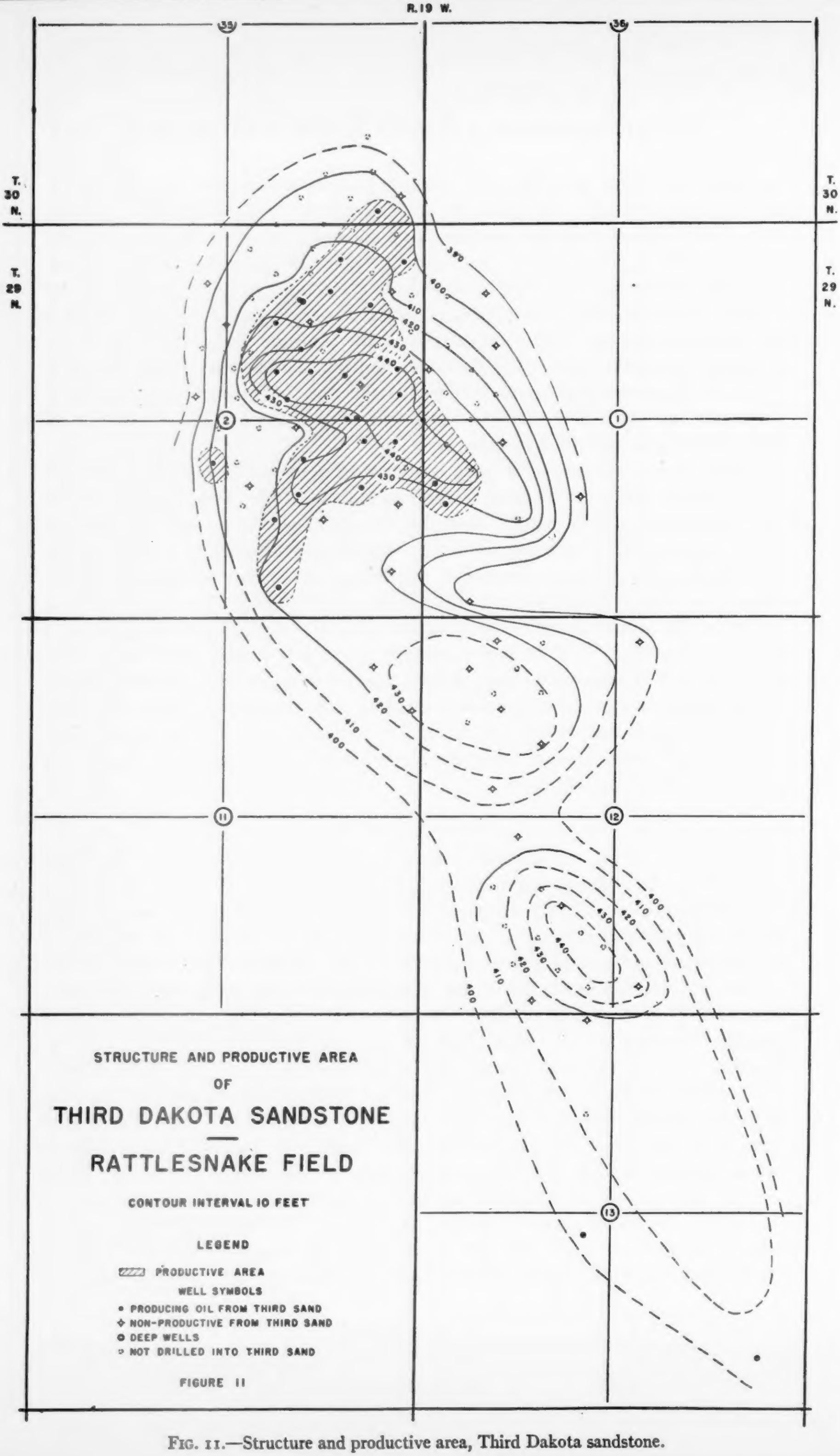


FIG. 11.—Structure and productive area, Third Dakota sandstone.

only two isolated wells producing from the second sand. The principal second-sand output is from the southernmost minor high in the field. The second sand is the only sand productive on this high area. The structure map on the top of the second sand indicates that this southernmost high area is about 30 feet lower in elevation than the highest parts of the northern part of the field. One of the two wells in the northern part of the field produces from the highest structural part; however, the other well produces from the lower part of the structure, although it is no lower structurally than the lowest well producing in the southern part of the field.

The area productive of oil from the third or lowermost member of the Dakota sandstone is shown by the shaded part of Figure 11. The productive area of the third Dakota sand is more regular than those of the other two sandstone members and seems to conform more closely to the structure contours than the others. Production is confined to the northernmost part of the field and is located principally on the structurally highest area. One isolated well produces from the third sand on the west side of the field.

There is surprisingly little overlap of the productive areas of the three Dakota sandstones. Only eight wells in the entire field produce oil from more than one sand. Two wells in the north part of the field produced from both the first and second sands, and six wells in that area produced from both the first and third sands. The overlap of the productive areas of the first and third sands occurs in the structurally highest part of the field. There is no overlap on the two minor highs in the southern part of the field, inasmuch as the southernmost high area produces solely from the second sand and the middle high area produces solely from the first sand. There is no third-sand production in the southern part of the field.

The vertical distribution of the oil accumulation in each of the sands is also irregular. In general, the oil occurs near the top of each sand, except where shale beds or the lenticular character of the beds has eliminated porosity near the top of the sandstone or has provided shale beds that have prevented the further upward migration of the oil. Cross section *AA'* (Fig. 12) shows the Dakota formation from the northernmost well in the field to the deep wells in the southern part of the field. The trace of this cross section is shown in Figure 8. Figure 12 also indicates occurrences of water in the Dakota sandstone as found during drilling operations. The occurrences of water are also distributed erratically through each of the sandstone members. Oil rarely occurs at the top of the first Dakota sandstone, probably because of the large amount of silt and clay and the abrupt change of facies at the top of the formation.

Thickness.—The average thickness of the Dakota sandstone is 200 feet, based on the records of 17 wells drilled through the formation. The thickness varies from 150 feet to 226 feet over the area of the field. The formation is the thinnest in the Bureau of Mines Rattlesnake well 1-G, in the southern part of the area. The variation in thickness is irregular and does not indicate any uniform pattern or trend of thickening or thinning over the field.

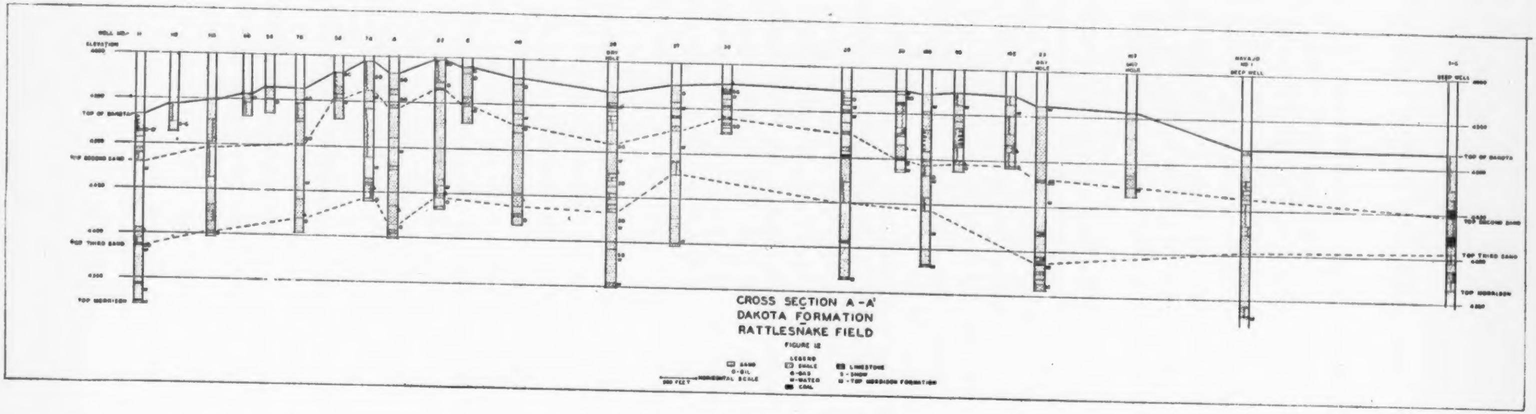


FIG. 12.—Cross section of Dakota sandstone.

The first or uppermost Dakota sandstone member has an average thickness of 63 feet based on records of 64 wells drilled through the formation. The thickness actually varies from 29 to 93 feet over the area of the field. The first sand reaches a thickness of 70 feet in the northern part of the structure in a band extending northeast and southwest perpendicular to the major axis of the structure and across the highest parts of the northern high structural area. North of this band the thickness decreases to 50 feet at the north edge of production. The first sand thins in a short distance southward off the structurally high area and attains a thickness of only 40 feet in a northeast-southwest band across the SE.¼ of Section 2. This thinning of the first sand is reflected on the structure-contour map of the second sand by a high structural area overlying the thinning of the first sand. This is indicative that the thinning took place in the lower beds of the first sand and was probably due to deposition over a local high area in the second sand. The first sand then thickens southward until it reaches a thickness of 80 feet in the southernmost minor high. Data from the two deep wells in the southern part of the area indicate that the sand thins again south of this minor high.

The second Dakota sandstone has an average thickness of 83 feet based on data from 51 wells. The thickness varies from about 40 feet to 128 feet, or from about ½ the average thickness to about 1½ times the average thickness. The most noticeable feature of the second sandstone is the abrupt thinning from the northern half of the field to the southern half of the field. The formation thins about 40 feet in a distance of ½ mile in the N. ½ of Sections 12 and 11. The greater part of the southernmost structurally high area has a thickness of less than 50 feet. The sandstone member thickens to about 60 feet at the Navajo well No. 1 and again reaches a thickness of only 41 feet in the Rattlesnake well 1-G. In the northern part of the area over the major structural high, the second sandstone member seems to be thick where the first sandstone member was thin and, in general, thins where the first sandstone members thicken. There is a transverse east-west belt across the central part of the northern part of the structure where the second sandstone is thinned. The second sandstone thickens outward in the northern part of the area until it reaches a total thickness of about 90 feet.

The third or lowermost Dakota sandstone member has an average thickness of 54 feet based on records from 18 wells drilled through the third sand. The thickness varies from 40 feet to 70 feet. The third sandstone thickens and thins erratically, and there are not sufficient data to show any uniform trends of thickening or thinning.

In most instances, the thinning of one bed is compensated by the thickening of another. There seems to be no relation between the thickness of the sandstone members and the presence of oil. The first sandstone member is not productive of oil in the thicker portions. The second or middle sandstone member is productive principally from the thinnest part of the sandstone.

The erratic porosity and permeability in the Dakota are indicated by the irregular occurrence of gas, oil, and water in each of the three sandstone members

of the Dakota formation, as shown in Figure 12. It is impossible to trace a porous zone for more than two or three well locations. Oil commonly occurs at a lower elevation in a structurally high well than it does in a structurally low well that may offset it. The development of the porosity is irregular in each sandstone member and is not continuous from one sandstone member to the other. The erratic porosity is further confirmed by the appearance of dry holes in well defined productive areas, as is the case in productive areas of sandstone members Nos. 1 and 3.

The barren area in the central part of the structural high as defined on the first sandstone member by Figure 8 is probably caused by the presence of silt in the sandstone or by cementation. The well logs indicate irregular shale and silt deposits in the first or uppermost sandstone member in this area. The cross section (Fig. 12) shows the lenticular development of shales.

OIL RECOVERY

The decline in oil production, as shown in Figure 7, indicates that the field is in the latter stages of depletion and should soon reach the stage of complete abandonment. Figures given herein for oil recovery should be near to the ultimate recovery from the field.

Reservoir pressure and temperature.—Information on reservoir pressures and temperatures is very meager. No information was obtained until March, 1938, when a test was made on well No. 5. This well has a total depth of 826 feet. The reservoir pressure was between 270 and 280 pounds per square inch and the reservoir temperature was indicated to be 75°F. The earlier wells drilled in the field were flowing wells and continued to flow even after making a large percentage of water.

Water encroachment.—The first water was produced in October, 1930, more than 6 years after the field was discovered. As indicated in Figure 7, the production of water increased steadily, although irregularly, during the life of the field until the water production exceeded the oil production in 1941. The irregular water production is due to completion of new wells and the abandonment of old wells that were making water. By March 1, 1943, all but 37 wells had been permanently abandoned. Three of these wells produced only water, leaving 34 producing oil wells at that time. Of these 34 wells remaining on production, 29 were productive from the first sand, 1 from the second sand, and 8 from the third sand. Four of these wells produced from both the first and third sands. The productive wells remaining at that time were centered around the higher part of the structure and around the inner edge of the barren area in the central part of the northern structure, as shown on the structure map of the first Dakota sandstone. Although the wells are spaced somewhat erratically, the general trend is to indicate water encroachment from the edge. Some abandoned wells lying within the remaining productive area, and the four wells producing from both the first and third sands

lie in the higher structural area. There is only one remaining productive well in the middle structural high, and produces from first Dakota sandstone.

On March 1, 1943, only one well was producing from the second sandstone in the field. This well was located on the east side of the southernmost minor high area. Originally, all but two of the wells producing from the second sandstone were located in this area. These data might indicate that the water drive or water encroachment came from the west side on this minor high.

All of the remaining producing wells in the third Dakota sandstone lie in the highest structural area, with the exception of production from the isolated well on the west wide of the structure. As mentioned above, four of the eight productive wells in the third sandstone also produce from the first sand.

The field probably had a very active water drive, as the bottom hole pressure is still high enough to cause a high water level in the wells that are producing water. A pump has been installed on the discovery well, which furnishes water for camp purposes, except for drinking water.

Well density.—In all, 120 wells have been drilled on this lease, 5 of which were deep wells. Of the 115 wells drilled for production from the Dakota sandstone, 55 were productive from the first sandstone member, 10 from the second sandstone member, and 26 from the third sandstone member. Eight wells produced from more than one sandstone member of the Dakota formation; two of them produced from the first and second sands and six from the first and third sands. On the basis of total productive area of each of the three sands and the number of wells that produced from each, the average well density is calculated to be 6.2 acres per well.

Oil recovery.—The productive area for each of the three sandstone members of the Dakota is outlined on Figures 8, 10, and 11. The planimeter was used to calculate the productive area in each sand. Using the net pay thickness, together with the calculated productive areas, a recovery figure of 527 barrels per acre foot was obtained. This is a very good recovery figure for the erratic character of the reservoir sandstone. The value of 527 barrels per-acre-foot recovery indicates that the percentage recovery for this reservoir probably lies between 60 and 70 per cent. This high recovery probably is due principally to the active water drive in the field and to the low viscosity of the high A.P.I. gravity oil.

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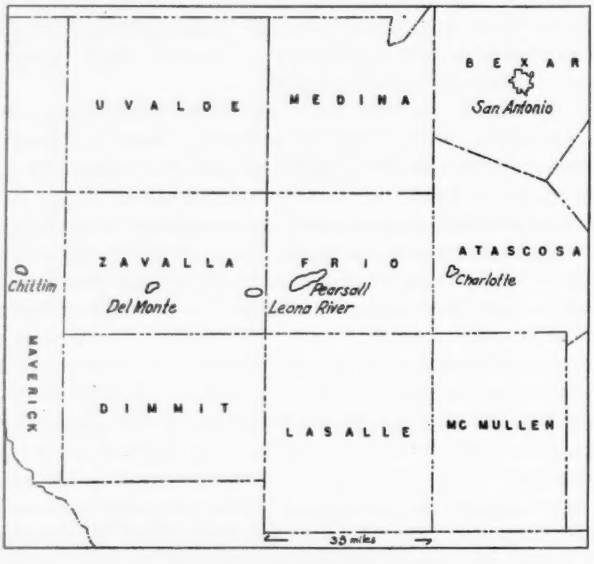
GEOLOGICAL NOTES

DEL MONTE FIELD, ZAVALA COUNTY, TEXAS[1]

GEORGE H. CLARK[2]
Houston, Texas

The Del Monte field is in south-central Zavala County, 6 miles north of Crystal City, Texas. It lies within the Rio Grande embayment province and near the axis of a regional depression commonly known as the Nueces syncline. The



INDEX MAP SHOWING LOCATION OF DEL MONTE FIELD AND ITS GEOGRAPHIC RELATIONSHIP TO NEAREST PRODUCING AREAS.

field name is derived from the deserted Del Monte townsite in the northeast corner of which the discovery well was drilled.

The new discovery represents the first commercial oil production for Zavala County and the most westerly oil field in this general province. It is the only field producing from the San Miguel formation. The nearest producing areas are the Chittim gas field in Maverick County, 24 miles west, the Leona River gas

[1] Manuscript received, February 22, 1947. Published with the permission of The Texas Company.

[2] Division geologist, The Texas Company.

field, approximately 23 miles east, and the Pearsall oil field in Frio County, 35 miles east.

The discovery well, The Texas Company's Northeast Farming Company No. 1, SE. 1/4 of Sec. 44, Cross "S" Ranch subdivision, was drilled to the total depth of 3,372 feet in the San Miguel formation. Gas- and oil-bearing sands of the San Miguel were penetrated from 3,300 to 3,372 feet and 7-inch casing was set on the top of the sand for completion. Upon failing to yield an appreciable amount of oil, the sand section was shot with 160 quarts of nitroglycerine, following which the well began to flow by heads through the casing, making 5–30 barrels of 19° gravity crude oil and approximately 600,000 cubic feet of gas per day. After several weeks of bailing in an attempt to clean out cavings, the well was finally completed on January 31, 1947, flowing initially, through a 7/32-inch choke, 5½ barrels of 19° gravity oil and 600,000 cubic feet of gas per day. In the meantime the company has drilled No. 1 Cross "S" Ranch-Tract No. 1 well as a southeast offset to the discovery and this test, being in a different fault segment and having a full section of the pay sand, was completed without shooting, flowing through 3/16-inch choke, 73.5 barrels of 25.9° gravity oil per day with a gas-oil ratio of 800:1. Open-hole completion was made in 30 feet of sand from 3,304 to 3,334 feet.

The Del Monte field is on the outcrop of the Queen City formation (Mt. Selman division of the Claiborne group) and the subsurface formations penetrated in the No. 1 Cross "S" Ranch-Tract No. 1 well, as identified from the electrical log and paleontological markers, are as follows.

	Depth in Feet
Eocene	
Queen City-Reklaw-Bigford	0– 680
Carrizo sand	– 836
Wilcox	–1,600
Midway	–1,945
Cretaceous	
Escondido-Navarro	–2,700
Olmos	–3,175
(Pay sands of Charlotte, Pearsall and Leona River fields)	
San Miguel-Taylor	–3,334
(Total depth of well)	
San Miguel sand	–3,334
(Pay sand of Del Monte field)	

The major structure at Del Monte is believed to be a northwest-southeast trending fold cut by several transverse faults. The feature was first recognized and mapped by the writer during the summer of 1936. Surface geology and shallow water-well data afforded the clues that led to the discovery of the prospect. On the basis of the writer's recommendations made in August and September of that year, the company immediately began assembling the large block of leases now held in the area. Subsequent geophysical surveys and supplemental surface and subsurface work done by Leroy Fish in 1939 and 1940 all confirmed the presence of a structural anomaly as originally outlined.

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DISCUSSION

PERMIAN CORRELATIONS[1]

PHILIP B. KING[2]
Washington, D. C.

The recent paper by Skinner[3] on the Permian of west Texas and southeast New Mexico is of interest in presenting a closely reasoned argument for correlation of the San Andres formation and the "Blaine of Texas" with a part of the Guadalupe series, based on detailed recent evidence; and for new and original observations in a little known and critical area bearing on the correlation problem—the west-facing scarp of the northern Guadalupe Mountains.

About a year ago, when Skinner's paper was announced, and shortly after publication of papers by Roth[4] and Clifton[5] on the same subject, the writer planned a rather extensive paper discussing the present status of Permian correlations, and presented the subject in outline form at the 1946 meeting of the Association in Chicago.[5a] On further thought, however, it appears that such a paper would serve no useful purpose; the writer has not worked in the region for some years, and has no observations to offer beyond those given in his paper of 1942.[6] Nevertheless, as Skinner's paper makes frequent reference to the writer's interpretations, perhaps he may be permitted to offer this brief discussion.

It is well to remind those unfamiliar with the problem that the matters in controversy are not new, but have been debated along much the same lines since the first work on the subject by Emil Böse and J. W. Beede, 25 years or more ago. Since that time, some geologists have interpreted the San Andres and "Blaine of Texas" of the Shelf area as equivalent to part of the Leonard series of the Delaware basin, and other geologists have interpreted the beds of the Shelf area as equivalent to part of the Guadalupe series of the Delaware basin. It is regrettable that such differences in interpretation should persist to this late date, for the problem is of more than local significance, and bears on the classification of Permian rocks throughout the Mid-Continent region, and over wide areas elsewhere in the United States. However, even with the great amount of stratigraphic and paleontological information now available, it appears that almost any interpretation offered creates as many problems as it solves, and that the question will remain with us for some years to come.[7]

[1] Manuscript received, February 24, 1947.
Published by permission of the director of the Geological Survey, United States Department of Interior.

[2] Geologist, United States Geological Survey.

[3] J. W. Skinner, "Correlation of Permian of West Texas and Southeast New Mexico," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 30 (1946), pp. 1847–74.

[4] Robert Roth, "Permian Pease River Group of Texas," *Bull. Geol. Soc. America*, Vol. 56 (1945), pp. 893–908.

[5] R. L. Clifton, "Permian Word Formation: Its Faunal and Stratigraphic Correlatives, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 29 (1945), pp. 1766–76.

[5a] Program of thirty-first annual meeting, Chicago, April 1–4, 1946: *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 30 (1946), p. 754.

[6] P. B. King, "Permian of West Texas and Southeastern New Mexico," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 26 (1942), pp. 535–763.

[7] A different appraisal is made by Clifton, who states that the evidence recently obtained "disposes of what some geologists regard as problems in correlation." (R. L. Clifton, *op. cit.*, pp. 1770–71).

The writer does not believe that the correlations presented by Skinner are proved. This is partly because the writer is the author of a previous and different correlation. However, it is also due to the fact that, while the new correlation explains many anomalies, it creates other anomalies.

Admittedly, Skinner's correlation more adequately explains the subsurface relations, but this was also true at the time of preparation of the writer's 1942 paper. A simple and workable interpretation of subsurface relations may provide a basis for day-to-day work, but may not in the end prove to be stratigraphically correct. A review of successive interpretations by subsurface geologists in a region undergoing intensive drilling will show a progression from more simple to more complex relations. Units once thought to be equivalent turn out to be of the same facies, but greatly different in age. Single units once thought indivisible are found to be subdivisible, or even to contain important unconformities. These considerations prompted the writer, when preparing his 1942 paper, to search for an interpretation more complex than the one now offered by Skinner.

On the paleontological side, most discussions of the Permian (including the writer's and Skinner's) have tended to overemphasize a few fossil groups, and to give too little consideration to the aspects of the faunas as a whole. This is understandable, for of all the Permian fossils, the fusulinids and ammonoids have received the most intensive study, and much less has been done on such groups as corals, brachiopods, pelecypods, and gastropods. Such intensive studies of a few groups have yielded quick returns, and have enabled us to obtain an over all picture of Permian correlations with considerable economy of time and effort, but such work is essentially reconnaissance in character. For verification, it should be followed up by comparable studies of the other fossil groups.

Use of the *Parafusulina rothi* fusulinid assemblage in correlation, and for distinguishing beds containing it (lower and middle Guadalupe in age) from beds beneath containing more primitive parafusulinids (Leonard in age) is perhaps justified, for the assemblage seems to be well characterized. However, such distinctions are between species of a genus, and of species within a single zone (that of *Parafusulina*), and are not between genera and between zones. They would seem to be somewhat less reliable than distinctions between the genera of the zone of *Parafusulina* and of the overlying zone of *Polydiexodina* (upper Guadalupe in age). Information already obtained may be sufficient to define the lower limit of the *Parafusulina rothi* assemblage, but it might possibly be modified by further discoveries.

To the writer, the ammonoid evidence presented by Clifton and quoted by Skinner, seems less substantial than the fusulinid evidence.

1. The occurrence of *Perrinites* described by Clifton in the basal limestone member of the Word formation of the Glass Mountains is no more than 140 feet above the top of the Leonard, or above the level from which the genus had previously been collected. It is in a unit whose fauna is otherwise transitional from the Leonard to the Word, and with many characters of each. The presence of a transitional unit between the thick, well characterized Leonard and Word units is hardly surprising, and does not seem to call for far-reaching revisions of interpretation.

Waagenoceras, the ammonoid which characterizes higher parts of the Word formation, is also reported from the basal limestone member at several localities in the Glass Mountains, but its exact relation to the beds containing *Perrinites* remains to be proved. There is a strong suspicion that both genera are near the respective lower and upper limits of their range. At any rate, *Perrinites* has so far not been found in the Glass Mountains, either in association with the main *Waagenoceras* ammonoid assemblage higher in the Word formation, or with the *Parafusulina rothi* fusulinid assemblage.

2. The ammonoids of so-called Guadalupe type in the "Blaine of Texas" of Skinner or Pease River group of Roth, in central Texas and Oklahoma, might well be of Leonard

age. Species of the genera cited occur sparingly or not at all in the Leonard, so that one would naturally tend to compare the central Texas and Oklahoma specimens with the Guadalupe species. Regarding these central Texas and Oklahoma genera, the following comments are in order.

a. *Pseudogastrioceras* is absent in the Leonard, but occurs in the Guadalupe. However, the genus occurs in beds of Leonard age in the Eastern Hemisphere[8] and ancestral genera are found in Texas in beds below the Leonard. Clifton's hypothesis that *Pseudogastrioceras* was a "trans-ocean migrant" in Guadalupe time, and hence indicative of Guadalupe age seems over-elaborate in the present state of knowledge. *Pseudogastrioceras* is a rather simple, generalized form and there is every reason to believe that the Leonard form, if it existed, would not differ greatly from the Guadalupe form.

b. *Agathiceras* is represented in the Leonard by a few specimens, which Miller and Furnish[9] identify as *Agathiceras girtyi* Böse? and *Agathiceras* cf. *A. girtyi* Böse. They therefore do not distinguish the Leonard form from the Guadalupe form as a separate species.

c. Specimens of *Medlicottia* from central Texas and Oklahoma have been variously identified. Plummer and Scott[10] identify one specimen as *Medlicottia burckhardti* (the Guadalupe species), and Miller and Furnish[11] another as *Medlicottia whitneyi* (the Leonard species). However, in a recent letter Miller states that "in most (if not all) cases it is not possible to distinguish Leonard from Word representatives of the genus *Medlicottia*." Citation of species of this genus would thus seem to have little meaning, at least for age determinations.

3. With the exception of the possible occurrence of both *Perrinites* and *Waagenoceras* in the basal limestone member of the Word formation, the two genera have never been reported together. In any given section where both *Perrinites* and *Waagenoceras* are present, *Perrinites* occurs beneath *Waagenoceras*, and disappears before the main zone of *Waagenoceras* is reached. According to Miller, the upper limit of *Perrinites* is an empirical matter. *Waagenoceras* is related to *Perrinites*, but is not in the direct line of descent; hence the disappearance of *Perrinites* near the base of the zone of *Waagenoceras* has little evolutionary significance. Nevertheless, the genus seemingly disappears at so nearly the same level in so many areas that its upper limit appears to be of stratigraphic significance. If the beds containing *Perrinites* in central Texas, Oklahoma, and New Mexico are of Guadalupe age, the occurrence of the genus there is unique.

According to Skinner, in the northern Guadalupe Mountains the San Andres formation contains the *Parafusulina rothi* fusulinid assemblage. He also notes the occurrence of other fossils, including *Dictyoclostus bassi* (*Productus ivesi*, in part, of older reports), and *Perrinites*. These other fossils form a distinctive assemblage, mainly of brachiopods and mollusks, whose salient features were indicated by Girty[12] about 30 years ago. Unfortunately, little study has since been made of this fauna. Much more detailed information is desirable, not only as to its character, but as to its affinities with faunas in adjacent regions.

[8] A. K. Miller, "Comparison of Permian Ammonoid Zones of Soviet Russia with Those of North America," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 22 (1938), pp. 1017–18.

[9] A. K. Miller and W. M. Furnish, "Permian Ammonoids of the Guadalupe Mountains and Adjacent Areas," *Geol. Soc. America Spec. Paper 26* (1940), pp. 9 and 14.

[10] F. B. Plummer and Gayle Scott, "Upper Paleozoic Ammonites in Texas," *Univ. Texas Bull. 3701* (1937), pp. 21 and 397.

[11] A. K. Miller and W. M. Furnish, *op. cit.* (1940), p. 19.

[12] G. H. Girty, "Paleontology of the Manzano Group of the Rio Grande Valley, New Mexico," *U. S. Geol. Survey Bull. 389* (1909), pp. 41–136.

Southeast of the San Andres area, and about 9 miles distant from the San Andres exposures on the west-facing scarp, Skinner reports another occurrence of the *Parafusulina rothi* assemblage in Last Chance Canyon. Here it lies above beds that contain Leonard fossils, and in association with numerous brachiopods and mollusks. From brief collecting trips, and from examination of reports on collections by other Geological Survey geologists, the writer concludes that the fossils associated with the *Parafusulina rothi* assemblage in Last Chance Canyon are of Word or middle Guadalupe type, and have no apparent resemblance to the brachiopods and mollusks of the San Andres fauna.

Much farther south, at the south end of the Guadalupe Mountains, the *Parafusulina rothi* assemblage occurs in beds of lower and middle Guadalupe age, but no lower. In this same area, according to available evidence, brachiopods and mollusks like those in the San Andres fauna occur in beds of Leonard age, but no higher.

If the features just outlined are correct, and if Skinner's proposed correlation is accepted, the Permian beds in the northern Guadalupe Mountains contain some remarkable lateral changes in the general aspect of the fauna, without a corresponding change in the fusulinids. In one area, the *Parafusulina rothi* assemblage occurs with the brachiopods and mollusks of the San Andres fauna, in other areas with very different brachiopods and mollusks of the Word or middle Guadalupe fauna. These inferred relations suggest that this area would be a profitable field, not only for detailed stratigraphic study, but also for detailed paleontological and ecological study. Such detailed study might reveal striking lateral changes in most of the fauna, with the fusulinids continuing unchanged. On the other hand, detailed knowledge of the fossils associated with the fusulinids might suggest the need for revision of existing concepts regarding the range of the *Parafusulina rothi* assemblage.

FACIES MAP AND LOG MAP[1]

T. B. HAITES[2]
Calgary, Alberta

In the February, 1947, issue of the *Bulletin*, T. H. Bower has an article: "Log Map, New Type of Subsurface Map." The writer would like to call attention to a similar map published in 1942. As a geologist of the Dutch collieries in the Netherlands during the war, he composed a map, which was called "Facies Map." The following quotations are taken from the description in the publication on this subject.

> For this purpose facies maps on a scale of 1:5,000 have been made. This is a composite map of all the available stratigraphical data, notably the development of the sediment between two coal seams i.e. between two prolonged vegetation periods. These data are assembled in vertical sections on the scale of 1:250. On the map the top of each section coincides as far as possible with the exact locality of the column observed. The data were obtained in cross-cuts, shafts, raises or sumps, underground borings, or bore holes from the surface.[3]

These data sources are comparable with Bower's "electric or other logs." The facies map is also a three-dimensional picture on a two-dimensional surface, essentially the same as Bower's log map.

[1] Manuscript received, March 3, 1947.

[2] Shell Oil Company, Ltd., 809 Fourth Street.

[3] A. A. Thiadens and T. B. Haites, "Splits and Wash-Outs in the Netherlands Coal Measures," *Mededeelingen van de Geologische Stichting*, Serie C-II-1-No. 1, p. 12. Ernest van Aelst, Uitgever, Maastricht, Netherlands (1944). Price, f. 5.20 (approx. $2.00).

With the facies map is an "Isopachytes Map," showing the isopachs which:

are based on data of the facies map and also on some data taken from contour plans of the coal seams. Moreover, the worked-out areas, taken from the Colliery plans, are shown, and the observed thicknesses of the coal seams concerned are given for these locations.[4]

Whereas the facies maps contain the facts and the isopachous maps personal interpretation, it was found more convenient not to combine them as Bower did on his log map. If Kodatrace is used and both maps are on the same scale one does not have difficulties as long as the maps are not published. If they are, it is necessary to combine them as Bower did or use the costlier method of printing two different maps, preferably on the same scale, as in the case of the facies maps and the isopachous maps.

As regards the contours, just as the isopachs are susceptible to personal interpretations, it was preferred to use two different maps, a base map and a transparent cover sheet on the same scale.

[4] *Ibid.*, p. 13.

CONODONTS AS PALEOZOIC GUIDE FOSSILS—A CORRECTION

SAMUEL P. ELLISON, JR.[1]
Midland, Texas

In the paper "Conodonts as Paleozoic Guide Fossils" in the January, 1946, *Bulletin*, Vol. 30, No. 1, p. 99, Barnes *et al.*[2] were cited as having found a Simpson (middle Ordovician) conodont fauna well down in the Ellenburger group (lower Ordovician). This fauna was included as an example of a stratigraphic leak. Barnes *et al.*[3] have pointed out that this was an erroneous citation. The Simpson conodont fauna, mixed with Devonian and Mississippian forms, was in a basal Mississippian detrital zone and should be properly classified as a stratigraphic admixture. Therefore, the Simpson fauna is an excellent example of a "ghost" or "phantom" fauna exactly as the term "phantom" was applied by Branson and Mehl.[4] Appreciation is expressed to H. A. Ireland for calling the writer's attention to the error.

[1] Stanolind Oil and Gas Company. Correction received, March 13, 1947.

[2] V. E. Barnes, P. E. Cloud, Jr., and L. E. Warren, "The Devonian of Central Texas," *Univ. Texas Bull. 4301* (1945), p. 176.

[3] V. E. Barnes, P. E. Cloud, Jr., and L. E. Warren, "Devonian Rocks of Central Texas," *Bull. Geol. Soc. America*, Vol. 58 (1947), p. 126.

[4] E. B. Branson and M. G. Mehl, "The Recognition and Interpretation of Mixed Conodont Faunas," *Bull. Denison Univ.*, Vol. 35 (1940), pp. 208; 209.

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REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library, and are available, for loan, to membeis and associates.

PETROLEUM DEVELOPMENT AND TECHNOLOGY, 1946 BY THE AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS

REVIEW BY W. A. VER WIEBE[1]
Wichita, Kansas

"Petroleum Development and Technology," *Trans. Amer. Inst. Min. and Met. Eng.*, Vol. 165 (1946). 289 pp. Published by the Institute, 29 West 39th Street, New York 18, New York. Price, $5.00.

This volume of the series called "Petroleum Development and Technology" for 1946 presents papers which were read at meetings held in Tulsa, Houston, Fort Worth, Los Angeles, and Chicago during the previous year (1945). They are a permanent record of one phase of activity of the Petroleum Division of the A.I.M.E. It covers only papers on petroleum research and production engineering. The statistical reports of production in various part of the United States, previously included, were published in a separate volume under the heading of "Statistics of Oil and Gas Development and Production."

Members of the A.A.P.G. will find much in this volume which will be interesting to them. The whole volume reflects clearly the present trend toward selective and specialized research in all phases of the oil industry. An article by Westbrook and Redmond of the Shell Oil Company in Houston, presents a new method for determining the porosity of well cuttings. This method provides a means of determining the bulk volume of a large number of particles (such as drill cuttings) by employing a capillary diaphragm for the removal of surplus surface liquids from saturated cuttings having pores of capillary size. Where cores are not availble, this method offers information of a very exact nature. Furthermore, it reduces the amount of error present in former attempts to determine porosity from drill cuttings.

Another article by A. C. Bulnes, of the Shell Company in Midland, Texas, gives valuable data on the application of the statistical method to the interpretation of core analysis of dolomitic limestones. Probability relationships are shown which connect the porosity and the permeability as well as the porosity and the fluid saturation. For this study, cores of the San Andres formation from Wasson as well as from the Clearfork formation from Fullerton were used. The term "invasion index" is defined in terms of the porosity and permeability data. This index is suggested as a basis for comparing wells as regards their suitability as fluid-injection wells. The graphs which accompany the paper are very illuminating. Discussion of the paper brought out the fact that a large percentage of the samples had less than one millidarcy of permeability. The author also mentions that much of the production from the Ellenburger is coming from zones of very low permeability. At Wasson and at Fullerton oil and water co-exist in the zones of low permeability.

In an article by Jackson and Campbell, of the Lane Wells Company of Dallas, Texas, some practical aspects of radioactivity well logging are presented. In fact this article is an excellent source of information for all geologists who may want to get a comprehensive picture of the technique as well as the value of using radioactive substances for correlation purposes. The authors also have included a very good bibliography for reference purposes.

[1] Professor of geology at the University of Wichita. Review received, February 26, 1947.

The ten articles of Chapter I entitled "Research" cover a wide variety of topics. One of the most valuable to our members is the one by H. G. Botset on "The Electrolytic Model and Its Application to the Study of Recovery Problems." The principle of the model is based on the fact that electrical flow through a conducting medium may be used to simulate homogeneous fluid flow through a permeable medium such as an oil producing zone. In order to produce visible ions and witness their motion, the author uses copper-ammonium ions which are deep blue in color to represent the input fluid. The sand is reproduced by an agar gelatin solution containing colorless zinc-ammonium ions. These zinc-ammonium ions which represent the fluid to be produced from the "sand" have the same mobility as the copper-ammonium ions. The two ions represent two fluids of equal viscosity. When the model is in operation photographs are taken of the "flood" at suitable time intervals. By this means it is possible to obtain in a few days, and at very small cost, qualitative comparison of the effect on recovery, of variation in the distribution and rates of operation of input and output wells in a given field. Edge-water encroachment into a field may also be studied. In brief, the advantages of the model are versatility, simplicity, low cost, speed, and the ability to give a visual demonstration.

A very helpful article on the production history of gas-drive pools is offered by Muskat and Taylor of the Gulf Research and Development Company of Pittsburgh. Calculations of pressure and gas-oil ratio histories have been made for conditions in which the oil viscosity, the gas solubility, the gas cap, the permeability-saturation of the rock, and the amount of connate water have been individually varied.

Among the other articles, the following will no doubt appeal to many of our members: "Behavior and Control of Natural Water-drive Reservoirs," by G. R. Elliott of the Phillips Petroleum Company at Bartlesville; "Method of Determining the Minimum Waiting-on-Cement Time," by R. F. Farris of the Stanolind Oil and Gas Company of Tulsa, Oklahoma; and "Core Analysis Based on Vacuum Distillation," by Beeson and Johnston, of the General Petroleum Corporation of California, Los Angeles, California.

MARINE ECOLOGY AS RELATED TO PALEONTOLOGY

The Sixth Report of the Committee on Marine Ecology as Related to Paleontology (1945–46) has recently been issued by the National Research Council. It is a bound mimeographed bulletin in 101 pages, containing material presented at the annual meeting of the Division of Geology and Geography.

The report contains an outline for a comprehensive Treatise on Marine Ecology and Paleoecology that the committee will prepare with the aid of interested specialists. Included also are eight signed reports. Four are annotated bibliographies of ecological studies that have been carried on in the Pacific area, the remainder are special ecologic studies. The report gives information on current and recently completed activities together with a current bibliography and summary reviews. Requests for copies should be addressed to the Division of Geology and Geography, National Research Council, 2101 Constitution Avenue, Washington 25, D. C., accompanied by a remittance of 50 cents for each copy desired.

RECENT PUBLICATIONS

ALABAMA-MISSISSIPPI

"Pre-Selma Upper Cretaceous Stratigraphy in the McCrary, McShan, Gordo, Samantha, and Searles Quadrangles, Alabama and Mississippi," by Louis C. Conant and D. Hoye Eargle. *U. S. Geol. Survey Prelim. Map 64*, Oil and Gas Investig. Ser. (February, 1947). Single sheet, 40×53 inches, with columnar section and explanatory text discussing lithology, thickness, and correlation of the rocks. Scale, 1 inch equals 1 mile. For sale by Director, Geological Survey, Washington 25, D. C. Price, $0.70.

ARGENTINA

*"Memoria de la Direccion General de Y. P. F. Correspondiente al Año 1945" (Y.P.F. Report of Operations for 1945), anonymous. *Bol. Inform. Petroleras*, Vol. 23, No. 267 (Y.P.F., Buenos Aires, November, 1946), pp. 325–90; illus. Data on Argentine geological and geophysical exploration, and progress of topographic mapping (Chapter 2, pp. 332–39). In Spanish.

BRAZIL

*"Ocorrências de Calcário no Rio Grande do Sul e Prospeção da Jazida de 'Vacacaí' no Munircípio de São Gabriel" (Occurrence of Limestone in the State of Rio Grande do Sul, and Prospecting the Deposit at Vacacaí in the Municipality of São Gabriel), by Viktor Leinz. *Estudos Brasileiros de Geologia*, Vol. 1, No. 1 (Fundaçáo Getúlio Vargas, Post Office Box 4081, Rio de Janeiro, Brazil, February, 1946). 46 pp., 17 figs., 4 tables, geological insert map of the State of Rio Grande do Sul. Price of this number, Cr $23.00. In Portuguese.

*"Investigaciones Petroliferas en el Estado de Bahia (Brasil)" (Petroleum Exploration in the State of Bahia, Brazil), by Avelino Ignacio de Oliveira. *Bol. Inst. Sudamercano Petroleo*, Vol. 2, No. 3, (Montevideo, Uruguay, December, 1946), pp. 449–70; 6 figs. (including geological sketch map, geological cross section, and oil and gas field development maps), 4 tables of oil and gas field development data. In Spanish.

CALIFORNIA

"The Monterey Formation of California and the Origin of Its Siliceous Rocks," by N. W. Bramlette. *U. S. Geol. Survey Prof. Paper 212* (1946). 57 pp., 19 pls. Address mail orders to Superintendent of Documents, Government Printing Office, Washington 25, D. C. Price, $0.60.

GENERAL

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*"Exploration and the Gravity Meter," by L. L. Logue and F. K. Fisk. *Oil and Gas Jour.*, Vol. 45, No. 42 (Tulsa, February 22, 1947), pp. 122–25; 8 figs.

"Preliminary Maps and Preliminary Reports Released by the Geologic Branch and the Alaskan Branch between January 1, 1945, and January 1, 1946 (List 2)," by W. H. Eckstein. Pamphlet obtainable from Director, Geological Survey, Washington 25, D. C.

Twentieth Century Petroleum Statistics, 1946, by DeGolyer and MacNaughton. Tables in this handbook cover crude production and proved reserves of countries and states, refinery production data, average life of wells, and statistics on drilling, dry holes, discoveries, oil wells, gas oil and fuel, lubricants, and related subjects. Published by DeGolyer and MacNaughton, Dallas, Texas. Price, $7.50.

Geology, Principles and Processes, by Wm. H. Emmons, Geo. A. Thiel, Clinton R. Stauffer, and Ira S. Allison. 2d ed. 451 pp. McGraw-Hill Book Co., Ltd. (New York). Price, $4.00.

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"Geologic Literature on North America, 1785–1918," by J. M. Nickles. Part 1, Bibliography. U. S. Geol. Survey (1923, reprinted 1947). 1167 pp. For sale by Superintendent of Documents, Government Printing Office, Washington 25, D. C. Price, $1.75.

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*"Investigation of Petroleum Resources in Relation to the National Welfare," by Joseph C. O'Mahoney. Final report of U. S. Senate Special Committee Investigating Petroleum Resources. *Senate Report No. 9, 80th Congress* (January 31, 1947). 59 pp. Government Printing Office, Washington, D. C.

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MID-CONTINENT

*"Directional Drilling in the Mid-Continent Area," by C. Phillip Collins. *Oil Weekly*, Vol. 124, No. 13 (Houston, February 24, 1947), pp. 32–34; 4 figs.

MIDDLE EAST

Saudi Arabia: With an Account of the Development of Its Natural Resources, by K. S. Twitchell. 192 pp., illus. Princeton University Press (Princeton, New Jersey, 1947). Price, $2.50.

NEW MEXICO

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ROCKY MOUNTAINS

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URUGUAY

*"Memoria Explicativa del Mapa Geológico del Departamento de Soriano" (Memoir Describing the Geological Map of the Department of Soriano), by Nicolas Serra. *Bol. Inst. Geol. Uruguay 32* (Montevideo, October, 1945). 42 pp., 4 pls. (8 photographs), colored areal geological map of the Department of Soriano, scale, 1:250,000.

U.S.S.R.

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"Correlation Between Allogenic Grade Size and Allogenic Frequency in Sediments," by Percival Allen.

"Heavy Residues of Soils from the Lower Ord River Valley, Western Australia," by Dorothy Carroll.

"Rhomboid Ripple Marks and Their Relationship to Beach Slope," by David F. Demarest.

"Experiments on the Development of Tracks in Fine Cross-Bedded Sand," by Edwin D. McKee.

"Sedimentary Petrography and the Oil Industry," by J. C. Griffiths.

"Committee Working on a New Rock-Color Chart for Field Use."

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 31, NO. 4 (APRIL, 1947), PP. 784-788

THE ASSOCIATION ROUND TABLE

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The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 979, Tulsa 1, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

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DISTINGUISHED LECTURE TOUR

The following geological groups heard Carey Croneis, president of Beloit College, deliver his lecture, "Geologic Crossroads," on the dates given.

March 10	Mississippi Geological Society	Jackson, Mississippi
11	Houston Geological Society	Houston, Texas
13	East Texas Geological Society	Tyler, Texas
14	Shreveport Geological Society	Shreveport, Louisiana
17	Tulsa Geological Society	Tulsa, Oklahoma
18	North Texas Geological Society	Wichita Falls, Texas
20	Dallas Geological Society	Dallas, Texas
21	West Texas Geological Society	Midland, Texas
22	Texas Technological College	Lubbock, Texas
29	Alberta Geological Society	Calgary, Canada
31	Wyoming Geological Society	Casper, Wyoming
April 2	Rocky Mountain Association of Geologists	Denver, Colorado
3	Kansas Geological Society	Wichita, Kansas
4	Illinois Geological Society and University of Illinois	Urbana, Illinois
5	Indiana-Kentucky Geological Society	Evansville, Indiana

WEST TEXAS GEOLOGICAL SOCIETY FIELD TRIP, MAY 30–JUNE 1

The West Texas Geological Society will conduct a field trip to the Guadalupe Mountains of Eddy and Otero counties, New Mexico, and Culberson County, Texas, May 30 to June 1, inclusive. Physical characteristics and stratigraphic relationships of reef structures of the Permian basin will be studied. Prominent features of the area to be covered include the highest point in Texas, Guadalupe Point, Carlsbad Caverns, Sitting Bull Falls, and El Paso Gap. V. E. Peterson, John W. Skinner, and P. D. Helmig will lead the trip. Discussion forums will be held the nights of May 29–30, in Carlsbad, New Mexico.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 31, NO. 4 (APRIL, 1947), PP. 789-791, 1 FIG.

MEMORIAL

GERALD FRANCIS LOUGHLIN
(1880–1946)

Gerald Francis Loughlin died suddenly of a heart attack on October 22, 1946, at the age of 65 years in the home of his daughter and her husband, Wilbur S. Burbank, in Washington, D. C. Thus was closed a long active career of a distinguished geologist who had served continuously on the United States Geological Survey since 1912. At the time of his death he was engaged in research of certain phases of metamorphic geology of New England and in the preparation of a new geologic map of Connecticut. This research, which he began early in his professional career, was resumed in 1944 when he relinquished the position of chief geologist which culminated a total period of 27 years in which he served in administrative positions.

He was born at Hyde Park, Massachusetts, on December 11, 1880. He received a Bachelor of Science degree in 1903 from Massachusetts Institute of Technology and a Ph.D. degree in 1906 from Yale University. In 1903 he was field assistant in a United States Geological Survey party and between that date and 1912 he held several positions, including instructorships in Massachusetts Institute of Technology and Tufts College, field assistant on the Connecticut Natural History and Geographical Survey, and junior geologist in Geological Survey parties in summers beginning in 1910.

Dating from 1912, when he received an appointment to the position of associate geologist on the staff of the Geological Survey, he moved to Washington and was given increasingly greater responsibilities. In 1913 he assumed the subjects of building stones and cements for the annual volumes on Mineral Resources, then prepared by the Geological Survey. In 1917 he was appointed chief of the non-metals section of the Division of Mineral Resources, and in 1918 was in charge of the section of metal resources as well as of stone and lime investigations. From 1920 to 1924 he was in charge of the entire Division of Mineral Resources, including its western offices. From 1924 to 1935 he was chief of the Section of Metalliferous Deposits, and from 1935 to 1944 was chief geologist. From the summer of 1944, when he relinquished the position of chief geologist, he served until his untimely death as special scientist and as a staff geologist advisor to the director and to the chief geologist. His career in the Government service thus spanned World Wars I and II and his endeavors, unstintingly, faithfully, and patriotically performed, contributed in large measure to the assembling of important data on the Nation's mineral supplies that were essential for victory.

Although Dr. Loughlin's interests in geology were broad, he specialized in the field of economic geology and pursued studies and wrote numerous reports on metalliferous deposits and on building stones and construction materials. In all these he presented his data in clear English and he weighed fairly possible alternative hypotheses and the opinions of others. His travels in the course of his studies and administrative work were made to numerous states, and he was recognized as one of the leading economic geologists of the United States.

As an administrative official, as well as a geologist, Dr. Loughlin was kind to all and was diplomatic and mild in expressing, whenever necessary, diverse views and criticism. As chief geologist he displayed friendly support and interest in the oil and gas work of the Geological Survey—in the formulation and prosecution of the individual projects and in the prompt handling of the manuscript reports for publication. His understanding, approbation, and praise of workers—their performance and reports—provided a constant

GERALD FRANCIS LOUGHLIN

source of encouragement and stimulation to individual workers and to me, the chief of the Fuels Section.

Dr. Loughlin's will and determination measured large and he accomplished much in whatever position he filled. During World War II, when the activities of the Geological Survey multiplied many fold in connection with the winning of the war, he performed an increasingly prodigious load of work. His duties, however heavy and arduous, were always performed with tremendous energy. His nature was happy, as shown by an ever-ready smile and by an apparent absence of worries. He found relaxation in visiting with companions, relatives, and friends, in play with his grandchildren, and in music—singing,

whistling, or playing the flute and piano. In the grid-iron type of annual shows of the Pick and Hammer Club of Washington he was a principal actor and musical director for thirty-odd years. Such a show has been the principal entertainment feature of several annual meetings of the Geological Society of America in Washington.

In addition to the personal satisfaction and to the words of appreciation that came to him from time to time from individuals as a reward for his full measure of endeavors and achievements he was honored by election to membership and offices in many local and national organizations, namely: Geological Society of Washington (president 1923), Washington Academy of Sciences (vice-president 1924), American Association for Advancement of Science, Geological Society of America (councilor), Society of Economic Geologists (president 1940), American Association of Petroleum Geologists, Mineralogical Society of America, American Institute of Mining and Metallurgical Engineers. He was a prominent and active member of the All Souls Unitarian Church of Washington, D. C., and belonged to the Cosmos Club in that city. He was a member of the Society of Sigma Xi.

In 1906 Dr. Loughlin and Grace Elizabeth French of Boston, Massachusetts, were married. He is survived by Mrs. Loughlin and their daughter, Mrs. Wilbur S. Burbank, and two grandsons, all of Washington, D. C.

Dr. Loughlin's friendly presence, his smile, and helpful counsel, which were a source of pleasure and mutual understanding to his companions and friends will live always in their memories and hearts.

HUGH D. MISER

WASHINGTON, D. C.
February 24, 1947

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 31, NO. 4 (APRIL, 1947), PP. 792-796

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

JOHN H. MAXSON has accepted a position with the Bay Petroleum Corporation as division geologist in the Rocky Mountain division. Formerly an assistant professor in the department of geology at California Institute of Technology, Maxson served in World War II as a lieutenant colonel in the Intelligence Section, Army Air Forces.

FRANCIS M. VAN TUYL, head of the department of geology at Colorado School of Mines, Golden, is a member of the engineering and research committee of the Interstate Oil Compact Commission.

JAMES W. KISLING, JR., after 22 years of service with the Amerada Petroleum Corporation, with special experience in structural geology and oil development in the Gulf Coast region, has resigned to do consulting work. His present address is 1343 E. 19th Street, Tulsa, Oklahoma.

ALBERT WYNN, El Dorado, Arkansas, is division geologist and acting chief geologist for Macmillan Petroleum Corporation.

The Houston Geological Society, on February 14–15, sponsored a field trip to Austin and the Central Mineral Region conducted by H. B. STENZEL of the University of Texas.

STANLEY G. ELDER, division geologist, Sun Oil Company, Evansville, Indiana, participated in a Men's Career conference at Oberlin College, Oberlin, Ohio, December 13 and 14, as the speaker and consultant for the field of geology and geography. Thirty-three different occupational fields were represented.

W. H. TWENHOFEL is a visiting professor in Yale University. After May 31, his address will be Madison, Wisconsin, until October 25, when he will return to Orlando, Florida.

MARCELLUS HENRY STOW of Washington and Lee University, Lexington, Virginia, has been appointed professor of geology on the Thomas Ball Foundation recently established by a gift of Mrs. Alfred I. du Pont of Wilmington, Delaware, made in connection with the university's bicentennial.

OLAF P. JENKINS has been appointed chief of the Division of Mines, California Department of Natural Resources. He has been chief geologist of the Division since 1929. Previously he was associated with the State departments in Washington, Arizona, and Tennessee, spent 3 years with the Standard Oil Company (N.J.) in the Dutch East Indies, and 7 years as professor of economic geology at the State College of Washington.

WILLIS G. MEYER and LEO A. ACHTSCHIN have formed a partnership, under the name of Meyer and Achtschin, to serve as consultants in petroleum geology and petroleum economics. Offices are in the Continental Building, Dallas, Texas.

R. H. BECKWITH has severed his connection with the University of Wyoming and is employed by the Union Oil Company of California. He may be addressed at 1421 Sheridan Street, Laramie, Wyoming.

S. F. SHAW spoke before the South Texas Section of the Association at San Antonio

on February 10. His topic was "Gas-lifting Oil Along the Gulf Coast in Fields Making Much Water."

JACKSON M. BARTON is divisional geologist with the Cooperative Refinery Association, 402 Schweiter Building, Wichita, Kansas. Formerly he was employed as a geologist by the Magnolia Petroleum Company, Midland, Texas.

GONZALO ACOSTA has joined with H. MADERO-PARIS in opening a consulting petroleum engineering office in Bogota, Colombia. Both partners are graduates of American universities, and until recently served in the Colombian Ministry of Mines and Petroleum.

ROBERT MCMILLAN, of Geophoto Services, Inc., Denver, Colorado, recently presented a paper on "Photogeology as an Aid in Oil Exploration" before the senior geology class at the Colorado School of Mines.

WILLIAM E. WALLIS and ROBERT M. STAINFORTH, International Petroleum Company, have moved from Guayaquil, Ecuador, to Peru; Wallis is stationed in Lima, and Stainforth in Talara.

REGINALD G. RYAN, independent consulting geologist, has moved his office from San Antonio to the Wichita National Bank Building, Wichita Falls, Texas.

KYE TROUT, JR., of Fort Worth, Texas, is employed by the University of Texas as assistant State coordinator of petroleum industry training.

MALVIN G. HOFFMAN, formerly with the Petroleum Administration for War, is in the Petroleum Division of the Department of State, Washington, D. C.

Pacific Petroleum Geologist is the title of a monthly news letter issued by the Pacific Section of the Association. In Volume 1, Number 1, dated January, 1947, MARTIN VAN COUVERING, as president of the Pacific Section, states that it is hoped that this "will serve as a medium of establishing a closer contact between members of the Section." Headed by LOYDE H. METZNER, the editorial staff presents a calendar of events, discussion of Association activities, personal items, and a selected bibliography of recent publications. Office of publication: Room 1116, 811 West 7th Street, Los Angeles 14, California.

CHARLES TAYLOR COLE, independent geologist of Midland, Texas, has been elected president of the International Junior Chamber of Commerce.

JOHN C. MILLER, Houston, Texas, has resigned as South Texas division geologist' The Texas Company, in order to accept a similar position with the Jergins Oil Company.

At the noon meeting, February 24, of the Houston Geological Society, L. L. NETTLETON, Gravity Meter Exploration Company, spoke on "Geological Model Studies." At the March 10 noon meeting, "Oil Reserve Provinces of the Middle East and Southern Soviet Russia" was presented by F. JULIUS FOHS, Fohs Oil Company. CAREY CRONEIS, Beloit College, Beloit, Wisconsin, spoke on "Geologic Crossroads" at the March 11 meeting.

Announcement is made of the twenty-third annual meeting of the American Association for the Advancement of Science, Southwestern Division, and the eighteenth annual meeting of the Colorado-Wyoming Academy of Science, at Colorado Springs, Colorado, May 1, 2, 3. DON B. GOULD, Colorado College, Colorado Springs, is secretary of the Colorado-Wyoming Academy of Science, and is chairman of the registration committee of the meeting. Titles of papers in geology and geography should be sent to MARGARET FULLER BOOS, United States Bureau of Reclamation, Denver, Colorado.

L. C. MORGAN, Morgan Acid, Inc., Wichita, Kansas, presented a paper on "The Hugoton Gas Field" at the March 3 meeting of the Tulsa Geological Society.

H. W. STRALEY, III, consulting geological and geophysical engineer of Washington, D. C., and Princeton, West Virginia, has jointed the staff of the International Bank to have charge of valuation of mining and oil properties. He may be reached at Box 5532, Friendship Station, D. C.

HARRY OBORNE, consultant, Colorado Springs, Colorado, spoke on "Oil Possibilities of the Las Animas Arch and Adjacent Areas of Eastern Colorado" at the February 26 meeting of the Rocky Mountain Association of Geologists.

At a joint meeting of the Oklahoma City Geological Society and the Provisional Oklahoma City Section of the American Institute of Mining and Metallurgical Engineers, February 25, two papers were presented: "Stratigraphy of the Hunton Limestone of the West Edmond Field," by J. T. RICHARDS, Gulf Oil Corporation, Oklahoma City, and "A Reservoir Study of the West Edmond Hunton Pool," by MAX LITTLEFIELD, A. C. GODBOLD, and L. L. GRAY, Gulf Oil Corporation, Tulsa.

The American Book Center for War Devastated Libraries is making a renewed appeal for American books and periodicals—for *technical and scholarly books and periodicals in all fields* and particularly for *publications of the past ten years*. It will especially welcome complete or incomplete publications of the Association. Ship your contributions to the American Book Center, c/o The Library of Congress, Washington, 25, D. C., freight prepaid, or write to the Center for further information.

The Association of Engineers, at the University of Liege, Belgium, celebrates this year its Centenary by means of a Congress and an Exhibition to which engineers and industrials are cordially invited. The Congress, which is entitled "Past, Present, and Future of Our Industry," will take place in Liege from Saturday, August 30, to Saturday, September 13, 1947. Fourteen sections are planned, including mines and geology.

HOBART E. STOCKING, of the department of geology of Oklahoma A. and M. College, Stillwater, Oklahoma, has been awarded the title of Professor Honorario of the Faculty of Sciences of the University of Costa Rica, where he was a State Department visiting professor in 1945.

Officers of the recently organized Turkiye Jeoloji Kurumu (Geological Society of Turkey) are: president, Professor HAMIT N. PAMIR, M. T. A. Instituso, Ankara, Turkey; vice-president, M. RECEP EGEMEN; secretary, GILAP OTKUN; treasurer, MEHLIKA TASMAN. The society plans to establish international relations with similar organizations abroad, by exchange of scientific correspondence and publications.

The Sun Oil Company has announced the promotion of KINGSLEY V. SCHROEDER to the position of chief geologist of its Beaumont division. Schroeder first entered the employ of the Sun Oil Company in the sales department in 1933.

GEORGE E. CARVER, JR., graduate student at the University of Oklahoma, was the speaker at the regular luncheon meeting of the Oklahoma City Geological Society, February 27. He talked on "The Geology of the Arcadia-Coon Creek Oil Fields," the subject of his M. A. thesis.

The South Louisiana Geological Society, in a meeting at the Majestic Hotel, Lake Charles, January 23, elected the following officers: president, BRUCE M. CHOATE, Atlantic Refining Company; vice-president, ROY PAYNE, Gulf Oil Corporation; secretary, W. FARRIN HOOVER, Stanolind Oil and Gas Company; treasurer, W. B. NEILL, Stanolind Oil and Gas Company.

WILLIAM T. O'GARA has accepted a post in the department of geology at Texas Christian University in Fort Worth. For several years he was with the Tropical Oil Company in Colombia.

WILLIAM C. BEDNAR has opened a consulting office in the Palace Building, Tulsa, Oklahoma. A petroleum engineer, he was formerly employed in Tulsa by Northern Ordnance, Inc.

WILFRED B. TAPPER is general manager of the electrical well services department of the Halliburton Oil Well Cementing Company, Duncan, Oklahoma.

RUSKIN H. MEYER is district geologist with the Macmillan Petroleum Corporation, El Dorado, Arkansas. He resigned from the Republic Natural Gas Company, Oklahoma City, Oklahoma, on February 15.

MALCOLM D. BENNETT, JR., formerly with the Continental Oil Company, is with the Standard Oil Company of Texas, Houston, Texas.

EDGAR K. SOPER has not resigned as associate professor of economic geology at the University of California at Los Angeles, as reported in the February *Bulletin*. He is still consultant for Signal Oil and Gas Company, Los Angeles, with which company he has been associated for some time.

JOHN C. GRIFFITHS has left the geological department, Trinidad Leaseholds, Ltd., Trinidad, B. W. I., to accept a position as assistant professor of petrography in the department of earth sciences, Pennsylvania State College, State College, Pennsylvania.

HENRY S. TAYLOR, JR., has accepted a position with the Creole Petroleum Corporation, Maracaibo, Venezuela. He recently resigned as geologist with The Texas Company.

CHARLES E. RIDDELL is working in the Karachi, India, office of the United Geophysical Company, Inc.

CHARLES H. DRESBACH has left Los Angeles to become assistant manager and chief geologist of the Colombian Gulf Oil Company in Bogota. He succeeds PAUL H. BOOTS, killed in a Colombian plane crash in February.

NORMAN HARDY, president of the Richmond Petroleum Company, recently has been in Colombia, S. A., in the interests of his company.

At the annual meeting of the South Texas Section of the Association at San Antonio, March 10, the following officers were elected: president, GUY E. GREEN, Santa Clara Oil Company; vice-president, VAN A. PETTY, JR., Petty Geophysical Company; secretary-treasurer, J. BOYD BEST, The Ohio Oil Company; member of executive committee, ROBERT S. MANN, Shell Oil Company.

RAE PREECE has been appointed field manager, drilling and production department, of the Hancock Oil Company of California, Long Beach, California. He retains the position of chief geologist which he has held for several years.

GEORGE H. CLARK is division geologist for the South Texas division of The Texas Company.

The Branner Geological Society of Southern California held its annual meeting at the California Institute of Technology, Pasadena, on March 5. The principal address was delivered by K. O. EMERY of the University of Southern California on "The Submarine Geology of Bikini Atoll." Officers for the year were elected: VERNON L. KING, consulting petroleum geologist, president; RICHARD H. JAHNS, California Institute of Technology, vice-president; and WILLIAM H. EASTON, University of Southern California, secretary-treasurer.

ROBERT E. GARRETT, consulting geologist and oil operator of Tulsa, Oklahoma, died on March 4, of a heart attack, while on a field trip near Bristow, Oklahoma. He was 59 years of age.

CARL W. HUBMAN was killed, February 15, in the crash of an airliner in Colombia. Employed by the Texas Petroleum Company, he had recently moved to Bogota, Colombia, from Corpus Christi, Texas. He was 42 years of age.

FRED B. PLUMMER, of the University of Texas Bureau of Economic Geology, at Austin, since 1928, died on February 17 at San Marcos, Texas, at the age of 60 years.

J. D. CERKEL, of the U. S. Geological Survey, Washington, D. C., spoke on "Petroleum Production and Resources of Japan" at the March 11 meeting of the Rocky Mountain Association of Geologists, Denver, Colorado.

H. SMITH CLARK, chief geologist for the southern division of the Sinclair Prairie Oil Company since 1927, has resigned to enter consulting work in Fort Worth, Texas.

BERNHARD H. LASKY, consulting engineer and geologist, has resumed his consulting practice with temporary offices at 3333 Charleston Circle, Houston 4, Texas.

DON W. JOPLING, president of Exploration Surveys Inc., has resumed his duties as active head of the company. Jopling has been in Alaska in a consultant capacity with Arctic Contractors, Inc., in active charge of the geologic program in Petroleum Reserve No. 4.

CHARLES E. DECKER, research professor of geology at the University of Oklahoma, Norman, has been elected an honorary member of the Alpha of Oklahoma chapter of Phi Beta Kappa. He joined the University faculty in 1916 as an instructor in geology.

GEORGE S. HUME has been appointed director of the Geological Survey of Canada, effective April 1. He began working for the Survey in 1915.

W. W. RUBEY, of the United States Geological Survey, Washington, D. C. and RAY P. WALTERS, of the Standard Oil Company (New Jersey), New York City, were designated by president Noble as representatives of the A.A.P.G. to attend the National Conference of the United Nations Educational, Scientific, and Cultural Organization, held in Philadelphia, March 24-26. The appointments were made at the invitation of Milton S. Eisenhower, chairman of the United States National Commission of the UNESCO.

New officers of the Wyoming Geological Association, Casper, are as follows: president, ROLLAND W. MCCANNE, The Ohio Oil Company; 1st vice-president, WAYNARD GEORGE OLSON, Continental Oil Company; 2d vice-president, THOMAS C. HIESTAND, Cities Service Oil Company; and secretary-treasurer, GEORGE STEELE, Northern Utilities Company.

Additional copies of the A.A.P.G.-S.E.P.M.-S.E.G. 1947 Field Trip Guidebook on Southern California, in connection with the 32d annual meeting of the Association at Los Angeles, March 24-30, are available at $2.65 each. The book contains approximately 132 pages and 16 full diagrams. Send check or money order to JOHN C. HAZZARD, Geological Department, Union Oil Company of California, 617 West 7th, Los Angeles, California.

KENNETH B. NOWELS, consulting petroleum engineer and geologist, is associated with the firm of Hill and Hill, Fort Worth, Texas. Nowels specializes in secondary-recovery methods.

EVERETT C. EDWARDS, formerly with the General Petroleum Corporation in Los Angeles, California, and with the Atlantic Refining Company in Bogota, Colombia, is practicing as a consulting geologist, with offices at 501 South Coast Boulevard, Laguna Beach, California.

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Vice-President - - - - William P. Winham
Box 2437 Terminal Annex, Los Angeles 54

Secretary-Treasurer - - - Clifton W. Johnson
430 Richfield Building, Los Angeles 13

Monthly Luncheons: First Thursday each month, Clark Hotel, 426 South Hill St., Los Angeles

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DENVER, COLORADO

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Geophoto Services, Inc.
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2nd Vice-President - - - - - A. W. Cullen
1024 Continental Oil Building
Secretary-Treasurer - - - - - - - N. W. Bass
U. S. Geological Survey, 314 Boston Bldg.

Evening dinner (6:30) and technical program (8:00) first Tuesday each month or by announcement.

FLORIDA

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TALLAHASSEE, FLORIDA

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Magnolia Petroleum Company
Vice-President - - - - - - - - B. B. Spaulding
The Texas Company, Box 21
Secretary-Treasurer - - - - - Lois J. Schulz
The California Company, Box 371

Meetings will be announced. Visiting geologists and friends are welcome.

OKLAHOMA

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Vice-President - - - - - - - - B. W. James
Phillips Petroleum Company, Box 958

Secretary-Treasurer - - - Murrell D. Thomas
The Texas Company, Box 539

Dinner meetings will be held at 7:00 P.M. on the first Wednesday of every month from October to May, inclusive, at the Ardmore Hotel.

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OKLAHOMA CITY, OKLAHOMA

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Carter Oil Company

Vice-President - - - - - - - - - - Harold J. Kleen
Skelly Oil Company

Secretary-Treasurer - - - - - - Frederick H. Kate
Shell Oil Company, Inc.
965 First National Building

Meetings: Technical program each month, subject to call by Program Committee, Oklahoma City University, 24th Street and Blackwelder. Luncheons: Every second and fourth Thursday of each month, at 12:00 noon. Y.W.C.A.

SHAWNEE GEOLOGICAL SOCIETY
SHAWNEE, OKLAHOMA

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Oklahoma Seismograph Company

Vice-President - - - - - - Henry A. Campo
Atlantic Refining Company

Secretary-Treasurer - - - - Marcelle Mousley
Atlantic Refining Company, Box 169

Meets the fourth Thursday of each month at 8:00 P.M., at the Aldridge Hotel. Visiting geologists welcome.

TULSA GEOLOGICAL SOCIETY
TULSA, OKLAHOMA

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Box 591, Stanolind Oil and Gas Co.

1st Vice-President - - - - - Russell S. Tarr
Independent, Beacon Building

2nd Vice-President - - - - - John C. Maher
U. S. Geological Survey

Secretary-Treasurer - - - - - John R. Crain
Consultant, 910 World Building

Editor - - - - - - - - - Robert F. Walters
Box 661, Gulf Oil Corporation

Meetings: First and third Mondays, each month, from October to May, inclusive at 8:00 P.M., University of Tulsa, Kendall Hall Auditorium. Luncheons: Every Friday (October-May), Chamber of Commerce Building.

PENNSYLVANIA

PITTSBURGH GEOLOGICAL SOCIETY
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Gulf Oil Corporation

Vice-President - - - - - - - S. S. Philbrick
United States Engineers

Secretary - - - - - - - - W. B. Robinson
Gulf Research and Development Company

Treasurer - - - - - - - - C. H. Feldmiller
Equitable Gas Company

Meetings held each month, except during the summer. All meetings and other activities by special announcement.

TEXAS

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Phillips Petroleum Company

Vice-President - - - - - - Graydon L. Meholin
Sinclair Prairie Oil Company, Box 1242

Secretary-Treasurer - - - - - Robert J. Gutru
Cities Service Oil Company, Box 350

Meetings: Luncheon 1st and 3d Wednesdays of each month, 12:00 noon, Herring Hotel. Special night meetings by announcement.

TEXAS

CORPUS CHRISTI GEOLOGICAL SOCIETY
CORPUS CHRISTI, TEXAS

President - - - - - - - - W. E. Greenman
The Texas Company, 902 Jones Building

Vice-President - - - - - - Dale L. Benson
Sinclair Prairie Oil Company, Box 480

Secretary-Treasurer - - - - - O. G. McClain
Consultant, 224 Nixon Building

Regular luncheons, every Wednesday, Petroleum Room, Plaza Hotel, 12:05 Special night meetings by announcement.

DALLAS GEOLOGICAL SOCIETY
DALLAS, TEXAS

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Meyer and Achtschin
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Vice President - - - - - - - John M. Clayton
Seaboard Oil Company
1400 Continental Building

Secretary-Treasurer - - - - - W. W. Newton
Geotechnical Corporation, Box 7166

Executive Committee - - - - H. C. Vanderpool
Seaboard Oil Company

Meetings: Monthly luncheons by announcement. Special night meetings by announcement.


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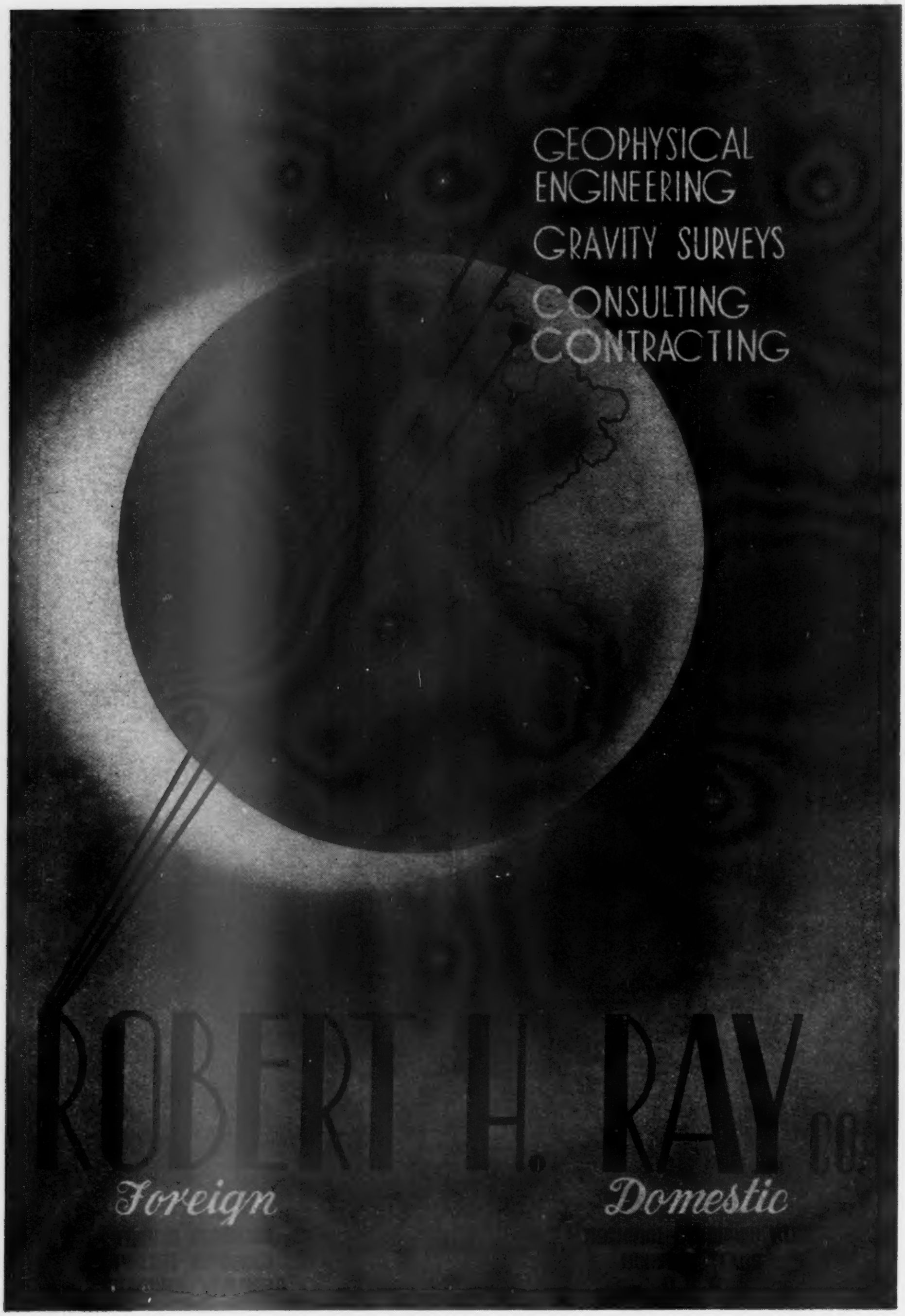
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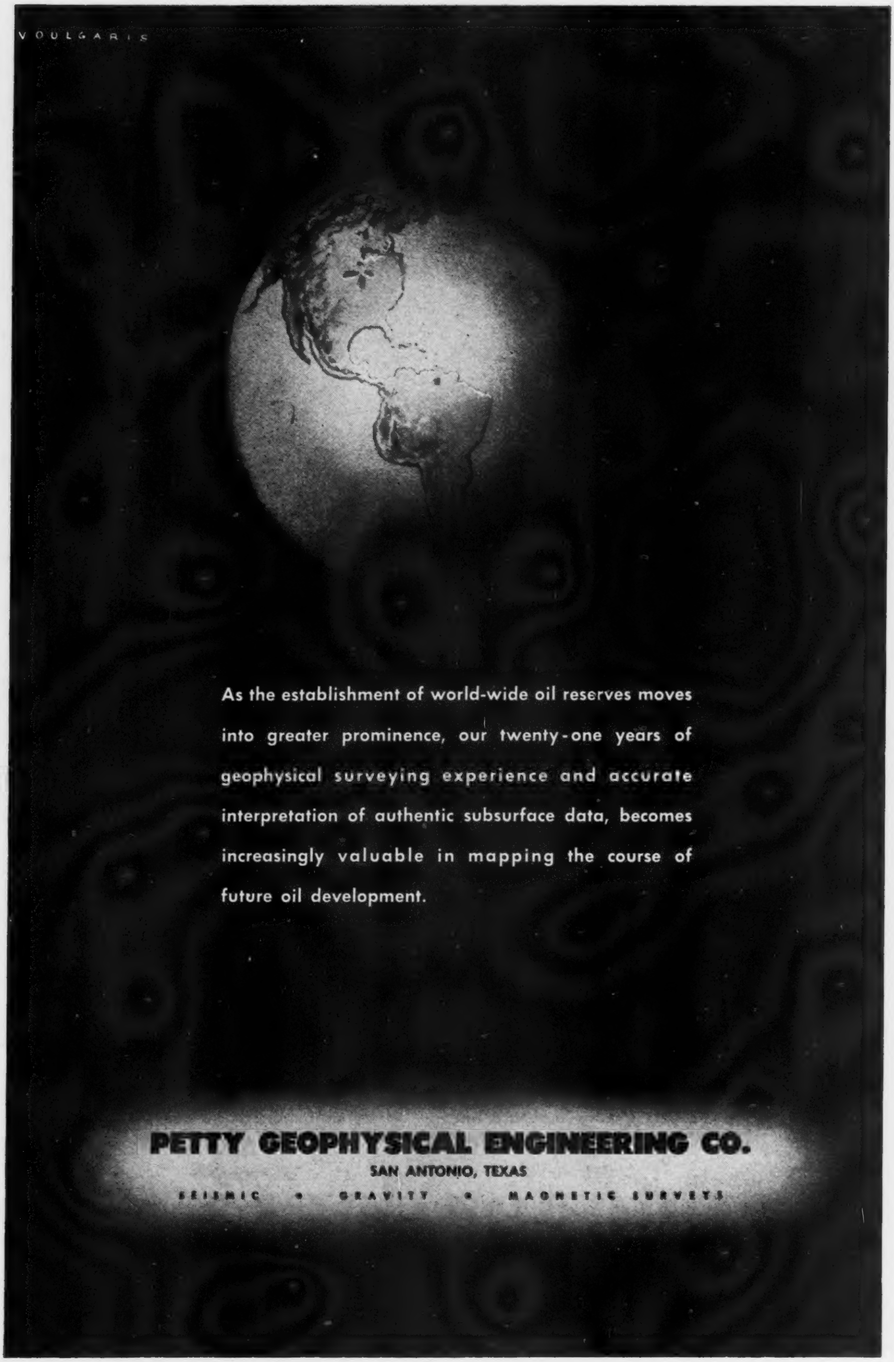
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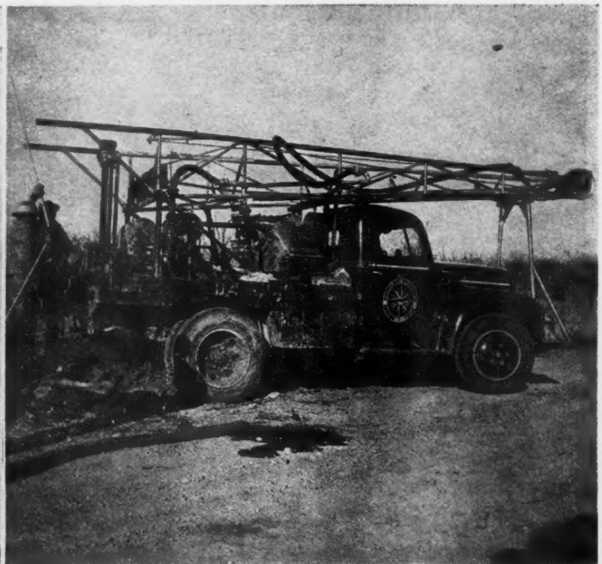

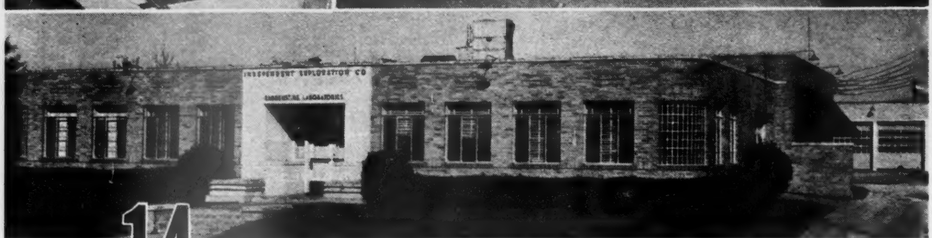

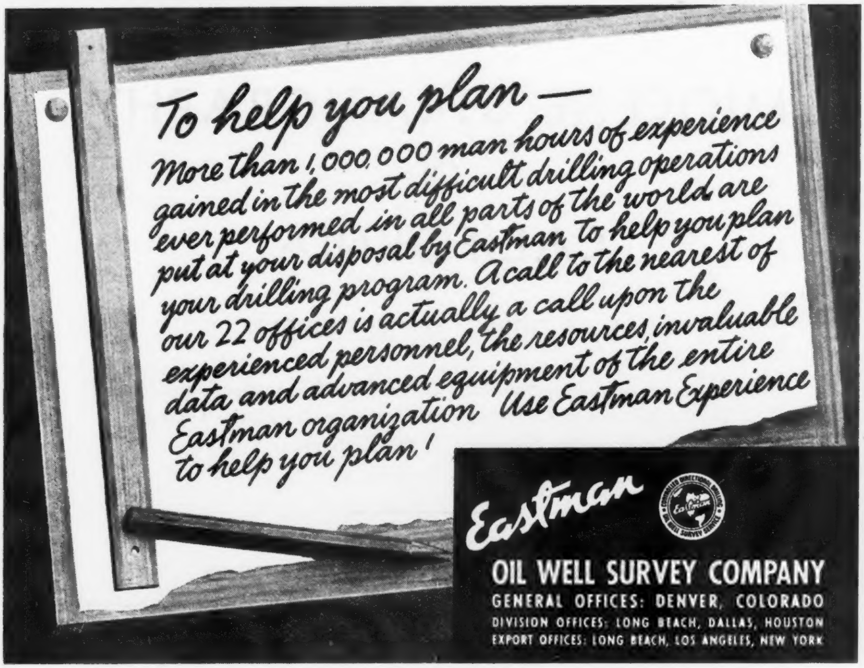

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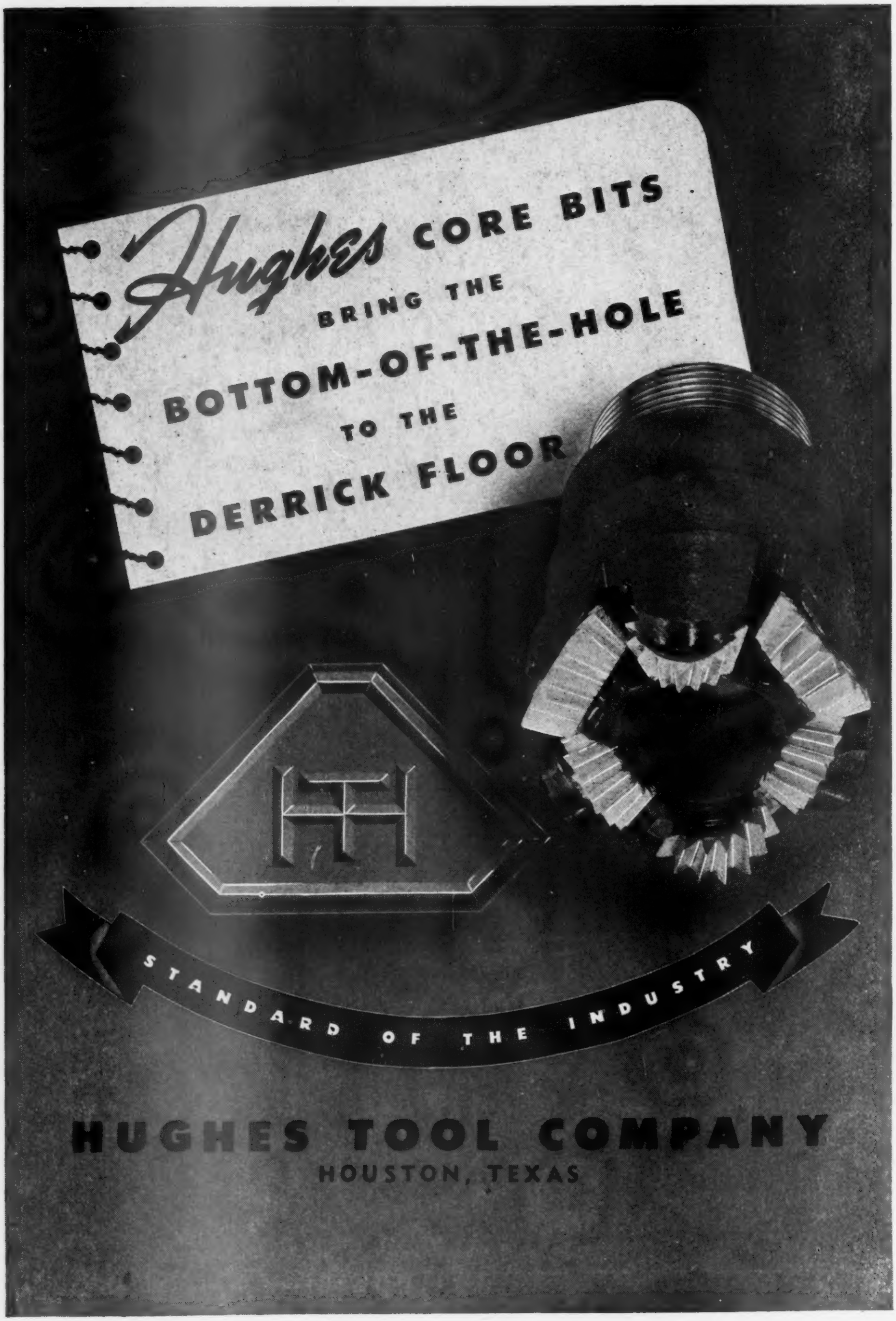

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